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EARLY PRE-CAMBRIAN GEOLOGY AND CORRELATIONAL PROBLEMS OF THE NORTHERN SUBPROVINCE OF THE LAKE SUPERIOR REGION

BY F. J. PETTIJOHN

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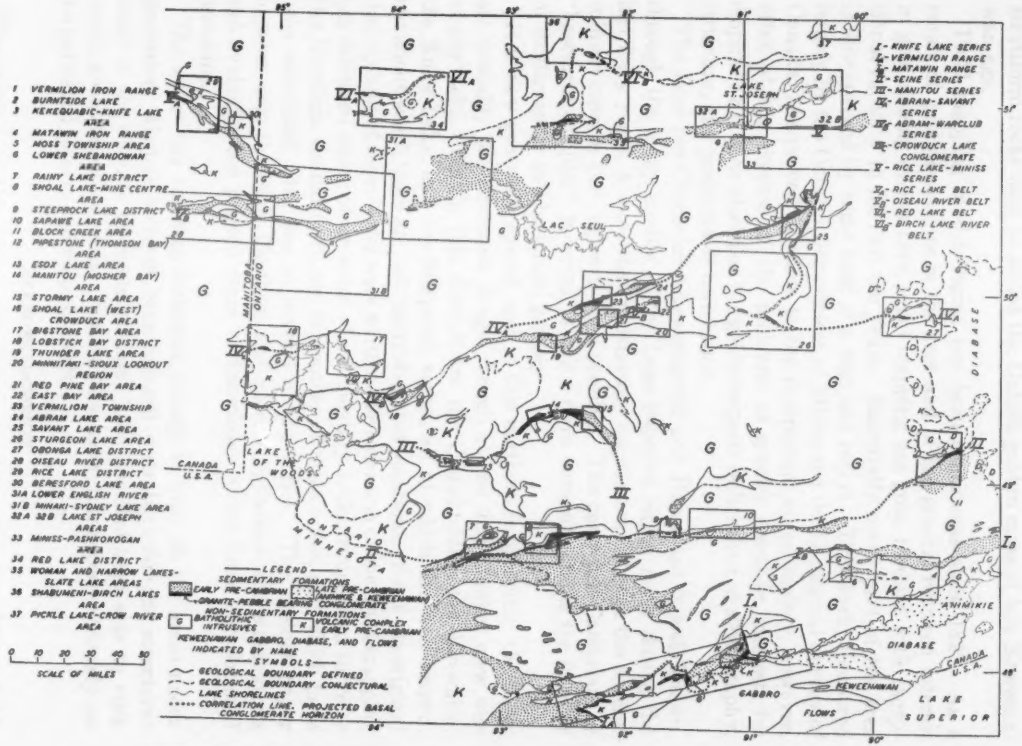
INTRODUCTION

STATEMENT OF THE PROBLEM

The region under consideration has been termed the Northern Subprovince of the Lake Superior pre-Cambrian. It is largely contained on the Kenora Sheet, Map No. 266A of the Geological Survey of Canada, though its natural boundaries lie outside the map limits. These might be considered to be the Mesabi Range on the south, the Lake Superior and Lake Nipigon basins on the southeast and east, the heavy cover of Quaternary clays and silts of the Lake Agassiz plain on the west, and an arbitrary line along Parallel 52, which separates approximately the area of more-detailed mapping from that of reconnaissance and exploratory surveys (Pl. 1). The region thus outlined is slightly larger than the State of Illinois. The bedrock, so abundantly exposed as a result of Pleistocene glaciations, consists, in the main, of granite, granite-gneiss, and related rocks, volcanic flows and pyroclastics, and sediments of various types, all of which belong to the early pre-Cambrian and accordingly exhibit varying degrees of metamorphism and are involved in structures of great complexity.

Only in the southeastern part of this subprovince are found rocks of late pre-Cambrian age—namely, the nearly flat-lying Animikie slates and



INDEX MAP OF NORTHERN SUBPROVINCE OF LAKE SUPERIOR REGION
Showing early pre-Cambrian sedimentary formations.

iron formation and the essentially horizontal sediments and diabase sills of the Keweenawan in the Thunder Bay and Nipigon areas. To these stratiform rocks may be added the Duluth gabbro mass of late Keweenawan age.

Field mapping in this region has been continuous since 1825. As a result of gold discoveries in the area and of the general renewed interest in gold mining everywhere, areal mapping has gone forward with exceptional rapidity in the last ten years. Essentially every part of the area is now covered by some kind of a map and report. This work, sponsored largely by the Ontario Department of Mines and the Geological Survey of Canada, has proved of value to the prospector; unfortunately, however, often at the expense of the problems of greater scientific interest, for emphasis has been placed on the gold prospects rather than on stratigraphy, structure, and problems of correlation.

The later pre-Cambrian (Keweenawan and Huronian) is well known, through the many studies in the Lake Superior region made during the last forty years. A somewhat satisfactory correlation between the several subprovinces in this region is even possible. The early pre-Cambrian, or "basement complex", however, is still a *terra incognita* and is the frontier of stratigraphic and historical geology.

It is now generally agreed that in this northern subprovince the rocks are probably pre-Huronian in age, though at one time another view was widely held. Within this district are the Coutchiching, the Keewatin, the Knife Lake, and the Steeprock series, all of which are well known, but about which there are still many disputed questions. Since the original descriptions of these series were written, the extension of the areal mapping has disclosed many other areas of sedimentary rocks, which bear more or less lithologic similarity to one or another of these series, and which have been correlated with one or several of the series. The present paper inquires into the basis for these and other correlations and summarizes and evaluates the present state of knowledge about these correlational problems.

The writer has not been fortunate enough to visit all the areas under discussion. He has, however, been engaged in stratigraphic and structural study in the vicinity of Sioux Lookout. He has also been able to visit briefly about ten other areas. For the remainder, it is necessary to rely on the published reports and maps of others.

ACKNOWLEDGMENTS

The writing of this paper was begun shortly after completing field work in Vermilion Township, made possible through a grant by the Geological Society of America. Publication was delayed, however, until after the seasons of 1935, and 1936 when, through grants from the National

Research Council, further field work was undertaken. The writer wishes to express his appreciation of this help, as well as of the cooperation of many other workers in this area.

GEOLOGY OF THE NORTHERN SUBPROVINCE

GENERAL STATEMENT

The early pre-Cambrian is composed of a complex assemblage of volcanics and sediments and their metamorphic equivalents, into which have been emplaced large batholiths of granite and related rocks. The volcanics or "greenstones" are commonly called Keewatin. The sediments that lie below the volcanics are designated Coutchiching, whereas the sediments stratigraphically above the volcanics are usually called Timiskamian or they are given a local series name, such as Seine, Knife Lake, or Abram. The sharp folding, combined with faulting along the formation boundaries, has often obscured the true relations between units. As will be shown, the sequence is actually more complex than as outlined. The key to the situation lies in part in the fact that the ubiquitous greenstones are not all of the same age, but belong to at least two very different periods of time. Probably, the several sedimentary series belong, likewise, to several different periods. The discussion of the several possible age relationships is postponed until the end of the paper. It seems most convenient to describe the geology of the northern subprovince by reference to the belts of sedimentary formations, six in number, which strike east to northeast, roughly parallel to one another, across the province (Pl. 1).

These sedimentary bands, each some scores of miles long, are in many places characterized by thick and persistent conglomerates of terrestrial origin. The sediments form the key to the stratigraphy of the subprovince, for some volcanics are subjacent, and other volcanics overlie these strata. The granites are in part older than the conglomerates, which carry abundant granite débris, and in part younger and intrusive into the conglomerate beds. From south to north, these belts may be called (after the principal sedimentary series of which they are composed): (1) Knife Lake belt, extending the length of the Vermilion iron range of Minnesota and the Matawin iron range of Ontario; (2) Seine belt, extending 250 miles from Rainy Lake, along the course of the Seine River, to the Block Creek area; (3) the Manitou belt, extending about 70 miles, from Schistose Lake to Stormy Lake; (4) Warclub-Abram-Savant belt, approximately 300 miles long, extending from Lobstick Bay of Lake of the Woods to Obonga Lake; (5) Rice Lake-Miniss belt, also about 300 miles long, extending from the Rice Lake area in Manitoba to the Miniss and Lake St. Joseph area in Ontario; and (6) Red Lake-Shabu-Kinewagons belt, present on Red Lake, in the Shabumeni-Birch lakes area, and along the Kinewagons River.

OGISHKE-KNIFE LAKE SERIES

Vermilion iron-range area.—Prior to 1900, most of the work on the geology of the Vermilion iron range was done by members of the Geological and Natural History Survey of Minnesota. These earlier reports were mainly descriptive notes on collected specimens, though by 1893, when Grant's important study of the Kekequabic Lake area appeared, the main outlines of the stratigraphy had been determined. Coincident with the development of iron-mining, the United States Geological Survey began field work, which resulted in 1903 in the monograph by J. M. Clements, *Vermilion iron-bearing district of Minnesota.* Clements reviewed the early literature at length. In 1911, the geology of the range was briefly reviewed in a monograph on the geology of the Lake Superior region by Van Hise and Leith. The geologic succession and history as reported by them have been accepted as essentially correct by most later workers in the district. The sequence was described as consisting of an early effusive volcanic series (Ely greenstone), overlain unconformably by a sedimentary series (Knife Lake). Both series are strongly deformed and unconformably overlain by a gently dipping slate-and-iron formation series (Animikie). Two periods of intrusive volcanism, one post-Ely and pre-Knife Lake and the other post-Knife Lake and pre-Animikie, were recognized.

Grout,[1] who has recently studied the igneous rocks, has shown that the granitic masses belong mainly to the later (Algoman) rather than to the earlier (Laurentian) period of intrusion. The views of Grout and a summary of the more recent work—up to 1926—of the Minnesota Geological Survey are contained in the bulletin on *the geology and magnetite deposits of northern St. Louis County, Minnesota.*

Since that date, J. T. Stark, J. W. Gruner, and their associates have been working in the Kekequabic and the Knife Lake areas, respectively. Grant and, later, Stark, recognized the abundance and importance of pyroclastic materials in the upper part of the Knife Lake series. Gruner, as a result of detailed structural study, noted that ellipsoidal flows heretofore believed to be pre-Knife Lake in age were stratigraphically above the slates and that "steeply dipping conglomerate, formerly believed to be Ogishke conglomerate, was deposited on the slates and flow." The name Grant conglomerate was applied to this younger deposit. The designation "Lower-middle Huronian" for the Knife Lake series has long been questioned, and recently, Leith [2] himself has discontinued its use.

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[1] F. F. Grout: *The Vermilion batholith of Minnesota,* Jour. Geol., vol. 33 (1925) p. 471.

[2] C. K. Leith: *The pre-Cambrian,* Geol. Soc. Am., Pr., 1933 (1934) p. 151-179.

C. K. Leith, R. J. Lund, and Andrew Leith: *Pre-Cambrian rocks of the Lake Superior region,* U. S. Geol. Surv., Prof. Pap. 184 (1935).

A major unconformity at the base of the Knife Lake sedimentary series represents a time interval during which the Saganaga granite (Laurentian)[3] intruded into the earlier lavas, and was denuded and weathered, thereby supplying detritus to the Ogishke conglomerate.

A period of widespread batholithic intrusion (Algoman) resulted in the emplacement of the Vermilion batholith,[4] the Snowbank granite,[5] the Kekequabic Lake granite,[6] and the Giants Range granite [7] shortly after the deformation of the Knife Lake slates and earlier strata. A major unconformity separates the sharply folded Knife Lake series from the younger, gently dipping Animikie beds [8] (Rove slates and Gunflint formation). Keweenawan diabase and gabbro [9] cut all the other formations of this district.

Just how much of the volcanics formerly mapped as "Ely greenstone" are interbedded with the Knife Lake or are younger in age, and how much is pre-Knife Lake, is not known. The greenstones cut by the pre-Knife Lake Saganaga granite are certainly older. The age of the greenstones northwest of Knife Lake and along the international boundary is in doubt, for they are in fault contact with the Knife Lake slates.[10] The greenstones southeast of Vermilion Lake are apparently pre-Knife Lake, for the Ogishke conglomerate is well developed at the boundary between the Knife Lake series and the Ely Greenstone complex.[11]

Grout [12] considered the greenstones south of Burntside Lake to be presedimentary. Here, the mica schist facies of the Knife Lake series dips under the greenstones and metamorphic equivalents. The structure, however, was proved by careful field mapping to be overturned.

Leith, Lund, and Leith, in their review of the geology of the Vermilion area,[13] write: "The Knife Lake series of the Vermilion district and its equivalents along the international boundary rest unconformably upon

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[3] F. F. Grout: *The Saganaga granite of Minnesota-Ontario*, Jour. Geol., vol. 37 (1929) p. 562-591.

[4] F. F. Grout: *The Vermilion batholith of Minnesota*, Jour. Geol., vol. 33 (1925) p. 467-487; *A peculiar shonkinite related to granite*, Am. Jour. Sci., 5th ser., vol. 9 (1925) p. 472-480; *A magmatic segregation in banded syenite in Minnesota*, Econ. Geol., vol. 20 (1925) p. 424-430; *Ages and differentiation series of the batholiths near the Minnesota-Ontario boundary*, Geol. Soc. Am., Bull., vol. 40 (1929) p. 791-809.

[5] C. W. Sanders: *A composite stock at Snowbank Lake, Minnesota*, Jour. Geol., vol. 37 (1929) p. 135-149.

Robert Balk and F. F. Grout: *Structural study of the Snowbank stock*, Geol. Soc. Am., Bull., vol. 45 (1934) p. 621-636.

[6] J. T. Stark: *The primary structure of the Kekequabic granite*, Jour. Geol., vol. 35 (1927) p. 723-733.

[7] I. S. Allison: *The Giants Range batholith of Minnesota*, Jour. Geol., vol. 33 (1925) p. 498-499.

[8] F. F. Grout and G. M. Schwartz: *The Rove formation and associated intrusives in northeastern Minnesota*, Minn. Geol. Surv., Bull. 24 (1933) 133 pages.

[9] F. F. Grout: *The lopolith, an igneous form exemplified by the Duluth gabbro*, Am. Jour. Sci., 4th ser., vol. 46 (1918) p. 516; *Origin of igneous rocks of Minnesota*, Jour. Geol., vol. 41 (1933) p. 196-218.

[10] J. W. Gruner: *Personal communication* (1935).

[11] J. M. Clements: *Vermilion iron-bearing district of Minnesota*, U. S. Geol. Surv., Mon. 45 (1903) p. 292-293.

[12] F. F. Grout: *Coutchiching problem*, Geol. Soc. Am., Bull., vol. 36 (1925) p. 356-358.

[13] C. K. Leith, R. J. Lund, and Andrew Leith: *op. cit.*, p. 16-18.

a basement of Keewatin and Laurentian rocks, are closely folded, are intruded and metamorphosed by granites of Algoman age. . . ." The Knife Lake series is composed characteristically of "banded and siliceous slates and graywackes . . . intercalated with which are many beds of conglomerate . . . , a thin iron formation . . . , basaltic flows and tuffs and various intrusives." This is essentially the view expressed earlier by Clements and by Van Hise and Leith. Unlike Clements, however, Leith, Lund, and Leith recognized the continental character of the sediments and admitted the importance of volcanic action in Knife Lake time. The presence of basaltic flows and tuffs other than "Keewatin" in age make it doubly important that the various greenstones commonly mapped as Keewatin be carefully re-examined for the purpose of determining their age relative to the main sedimentary series of the region.

Matawin iron-range area.—The geology of the Matawin iron range is generally similar to that of the Vermilion iron range in Minnesota. The geology of this range was early summarized by McInnes,[14] Coleman,[15] and others. In 1926, Tanton published a detailed survey of the eastern part of this district. In this area are a series of banded mica schists and paragneisses, called Coutchiching by Tanton, a series of lavas, pyroclastics, and iron formation (Keewatin), a post-lava sedimentary series composed of granite-pebble-bearing conglomerates, slates, and iron formation, and a widespread series of batholithic intrusions believed to be later than all the others. Nearly horizontal Animikie sediments rest unconformably on the much disturbed earlier strata.

Banded mica schists, areally extensive, occur all along the northern border of the volcanics and lie between these and the granites to the north. Because of lack of conglomerate at the contact [16] and because the post-lava series (Windigokan of Tanton) "is more closely associated with the Keewatin than with the mica schists", Tanton believes the mica schists are pre-volcanic, or Coutchiching, in age. Tanton more recently reports gradation in texture in beds of the mica schist series adjacent to an unfaulted contact with the volcanics (here designated Keewatin) near Kashabowie, which indicates that the lavas are superimposed on the mica schists. This was, in his opinion, the best evidence on the succession.[17] The post-volcanic sediments are, in several small areas, elongated in an

[14] William McInnes: *Report on the geology of the area covered by the Seine River and Lake Shebandowan map-sheets*, Geol. Surv. Canada, Ann. Rept., vol. 10, pt. H (1899) p. 65.

[15] A. P. Coleman: *Iron ores of northwestern Ontario*, Ontario Bur. Mines, 11th Ann. Rept., vol. 11 (1902) p. 130.

[16] Tanton nevertheless shows on his map (No. 2069), which accompanies this report, "conglomerate, greywacke, etc." (classed as Windigokan) along the contact in Goldie Township. Moreover, here the conglomerate carries abundant granite pebbles (p. 120). This belt, half a mile to a mile wide, extends westward from Goldie Township along the contact for more than 7 miles.

[17] T. L. Tanton: *Personal communication* (1935).

eastward direction in a zone within the northern part of the belt of volcanic rocks. Interbedded with the normal sediments are some stratified tuffs. Tanton correlates these sediments with the Windigokan series east of Lake Nipigon, and with the Steeprock series.

In 1929, Watson described granite-pebble-bearing conglomerates with associated arkose and graywacke some 12 miles farther west, just south of Lower Shebandowan Lake, evidently an extension of those described by Tanton from the eastern Matawin Range. Watson also described the Moss Township area just west of Shebandowan Lake. Here, the volcanics, both acid and basic, are not associated with an important sedimentary series. As elsewhere, batholithic granites cut the bedrock complex.

Tanton made brief mention of these early pre-Cambrian rocks in his report on the Fort William and Port Arthur area and in another paper,[18] but no new information relative to these early pre-Cambrian rocks is given in either reference.

SEINE SERIES AND COUTCHICHING PROBLEM

Rainy Lake area.—Since Lawson first described and named the mica schists and fine paragneisses at Coutchiching Rapids on the Rainy River in 1887, much has been written regarding the stratigraphic position of these beds. In fact, so much has been written that an adequate summary would make a lengthy paper in itself. Merritt's report, published in 1934, contains an excellent statement of the controversy, with reference to the type area and to the extensions of the "Coutchiching" paragneisses eastward up the course of the Seine River. However, many attempts have been made to apply the term Coutchiching to various bedded rocks of similar lithologic character and supposed pre-"Keewatin" age in other places in this part of the Canadian Shield. Before the evidence can be summarized, it is necessary to review briefly the present status of the question in the type area and along the Seine River.

The so-called Coutchiching series, consisting of distinctly stratiform mica schists and fine-grained gray, evenly bedded paragneisses, extends eastward from Rainy Lake for about 150 miles to Lac des Mille Lacs. The stratigraphic position of these schists has been under discussion since the time of their first description. McInnes,[19] Grout,[20] Bruce,[21] Tanton,[22]

[18] T. L. Tanton: *Stratigraphy of the northern subprovince of the Lake Superior region*, Geol. Soc. Am., Bull., vol. 38 (1927) p. 731-738.

[19] William McInnes: *Report on the geology of the area covered by the Seine River and Lake Shebandowan map sheets*, Canada Geol. Surv., Ann. Rept., n.s., vol. 10, pt. H (1899) p. 65.

[20] F. F. Grout: *Coutchiching problem*, Geol. Soc. Am., Bull., vol. 36 (1925) p. 351-364.

[21] E. L. Bruce: *Coutchiching rocks of the Bears Pass section, Rainy Lake, Ontario*, Royal Soc. Canada, Pr. and Tr., 3rd ser., vol. 19, sec. 4 (1925) p. 43-46; *Gold deposits of the Kenora and Rainy Lake River districts*, Ontario Dept. Mines, Ann. Rept., vol. 34, pt. 6 (1925) p. 1-42.

[22] T. L. Tanton: *Recognition of the Coutchiching near Steeprock Lake, Ontario*, Royal Soc. Canada, Tr., vol. 20, sec. 4 (1926) p. 48; *Stratigraphy of the northern subprovince of the Lake Superior region*, Geol. Soc. Am., Bull., vol. 38 (1927) p. 731-748.

Hawley,[23] and Gill [24] have all written on the subject. Merritt restudied the whole problem.

Opinion relating to the position of these paragneisses is divided. McInnes, Bruce, and Tanton follow Lawson in placing these schists below the "Keewatin" volcanics; Grout and Merritt place them above the "Keewatin" and consider them to be a metamorphic facies of the Seine series. Hawley reached no final conclusion but favored a post-"Keewatin" age; Gill, likewise generally non-committal, favors a pre-"Keewatin" position.

As evidence of the pre-"Keewatin" age of these beds, Lawson, in his re-study of the Archean geology of Rainy Lake, published in 1913, cited the general map relations and the structural attitude or direction of dip. In the Rice Bay area, for example, the mica schists occupy a closed belt of flattened oval shape, encircling a central mass of intrusive granite-gneiss, and it, in turn, is encircled by "Keewatin" hornblende schists. The mica schists have a quaquaversal dip; the structure thus appears to be a dome, the mica schists and the hornblende schist being interbedded at the contact between the two. Also, at Bears Pass, between Rainy Lake and Redgut Bay, plotting of strikes and dips of the bedded mica schists discloses an apparent anticline in which the schists wrap around, and dip away from, an intrusive mass of granite gneiss, and dip under the "Keewatin" on either flank of the structure.[25] Apparent interbedding is here also, at the contact between the "Keewatin" and the Coutchiching and this, together with a lack of conglomerate, has been cited by Lawson as corroborative evidence of the superposition of the "Keewatin" on the mica schists. The main southern area of Coutchiching on Rainy Lake (which includes the type locality) presents no positive evidence of its position below the "Keewatin." The position of the Cliff Lake conglomerate, carrying "Keewatin" débris between the "Coutchiching" on the south and the "Keewatin" on the north, noted in 1905 by Van Hise and the other members of the special committee for the Lake Superior region, proves quite the contrary. Lawson's explanation of this conglomerate as an infolded syncline of Seine age is not convincing, especially in the light of Grout's Coutchiching studies. On Niel Point, about 14 miles west of Cliff Lake, Lawson had originally mapped an extension of the supposed closely appressed syncline. The sequence on Niel Point,

[23] J. E. Hawley: *"Seine" or "Coutchiching"?* Jour. Geol., vol. 38 (1930) p. 521-547.

[24] J. E. Gill and J. E. Hawley: *"Seine" or "Coutchiching"?* (discussion), Jour. Geol., vol. 39 (1931) p. 655-669.

[25] E. L. Bruce: *The Coutchiching rocks of the Bears Pass section, Rainy Lake (Ontario)*, Royal Soc. Canada, Pr. and Tr., 3d ser., vol. 19, sec. 4 (1925) p. 43-46

Bruce remapped this area and came to essentially the same conclusions as Lawson except that Bruce believed Lawson mistook later sill-like intrusions near the Keewatin-Coutchiching contact for interbedding; of these two units.

based on a study by Grout of cross-bedding in the conglomerates and associated arkosites, is homoclinal from north to south, the conglomerate and arkosite member occupying a position between the older "Keewatin" on the north and the mica schist of the "Coutchiching" on the south. Merritt concurs in this interpretation. It would seem, therefore, that by far the largest volume of the Coutchiching is post-Keewatin.

Some considerable doubt exists relative to even the Bears Pass section. The mica schists, which are here greatly recrystallized, occur in a less metamorphosed condition on Morton and Dude islands of Swell Bay, 1 or 2 miles south and southwest of the entrance to the pass. Here, Grout, and later, Merritt, discovered graded bedding in the "Coutchiching", demonstrating a structural orientation of the beds incompatible with any theory of a pre-"Keewatin" age.

Seine River.—East of Rainy Lake, along the lower course of the Seine River, the relations are complicated by close folding, involving the "Keewatin" volcanics, the Seine conglomerates and quartzites, and the so-called Coutchiching. Here, Merritt has seen the actual "Keewatin"-Coutchiching contact, which shows no signs of faulting and, in many places, has a thin intervening conglomerate. Near the contact, in some places within a few feet, he has found graded bedding, indicating a superposition of the mica schists on the "Keewatin." East of La Seine, the great body of mica schists and paragneisses—an uninterrupted eastward extension of the "Coutchiching" from the south shore of Rainy Lake—is separated from the "Keewatin" on the north by an even east-west-trending line. The interpretations of the relations here were much confused by the mapping of McInnes and Lawson. The contact between the true volcanics (Keewatin) and the disputed mica schist assemblage was first correctly defined by Grout in the vicinity of Jackfish Lake and later was substantiated by Tanton,[26] Hawley,[27] and Merritt. At Jackfish Lake, along the contact, a conglomerate separates the two series. Merritt has mapped similar patches of conglomerate at, or near, the contact of Pike Lake, Perch Lake, on the Atikokan River just above its confluence with the Seine River. In other places, conglomerate is missing from the boundary. Tanton,[28] however, noted that the top of the sedimentary beds, as determined from graded bedding, faced north. Merritt states that, along the same contact, the beds face north in some places and south in others. These anomalies are explained by assuming the contact to be a fault

[26] T. L. Tanton: *Stratigraphy of the northern subprovince of Lake Superior region*, Geol. Soc. Am., Bull., vol. 38 (1927) p. 731-748.

[27] J. E. Hawley: *op. cit.*, p. 521-547.

[28] T. L. Tanton: *Recognition of the Coutchiching near Steeprock Lake, Ontario*, Royal Soc. Canada, Tr., vol. 20, sec. 4 (1926) p. 48.

line. Such an interpretation was made by Hawley,[29] who found much corroborative evidence of its correctness in the Sapawe Lake area. The case for the Coutchiching as a pre-"Keewatin" series can hardly be established in this region because of these structural complexities.

In summary, it may be said that, in the Rainy Lake and Seine River regions, the Coutchiching can hardly be considered proved to be a pre-"Keewatin" series or system. By far the greater part of the mica schist assemblage originally mapped as such is definitely post-"Keewatin." There remain only the much altered schists of Rice Bay and the Bears Pass. Even in the latter area definite evidence is inconsistent with a pre-"Keewatin" age of the mica schist, though, owing to intrusion and metamorphism, the true relations are still obscure.

The geologic column of the Rainy Lake and Seine River region, then, begins with the complex of greenstones and green schists of volcanic origin with minor interbedded sediments that have been designated "Keewatin" by all investigators. Intrusive into these are the "Laurentian" granites, of which only one (Shoal Lake), or perhaps two, is definitely known. The Laurentian or pre-Seine age of the Shoal Lake mass has been questioned by Parsons.[30] Bruce and Merritt made a careful re-study of the contact with the Seine conglomerate and confirmed Lawson's original determination of Laurentian age. The writer also has seen the contact and agrees with Merritt, Lawson, and Bruce. More recently Tanton, in a preliminary report on the Mine Centre area, refers to the Shoal Lake granite and porphyry mass as post-Seine in age.

There is no good proof that the other granites mapped as Laurentian by Lawson are truly Laurentian in age, as they are in contact only with the "Keewatin" schists. The lithologic criteria of Lawson [31] are of doubtful value. Resting unconformably on these earlier rocks are the Seine sediments, the lowest member of which is the thick and persistent Seine conglomerate. This grades upward and along the strike into quartzite, graywackes, and slates, locally converted to mica schist and paragneiss by the widespread post-Seine or "Algoman" granites.[32] A few large diabase dikes cut the granites and are, perhaps, Keweenawan.[33]

[29] J. E. Hawley: *op. cit.*, p. 521-547; *Geology of the Sapawe Lake area, with notes on some iron and gold deposits of the Rainy River district*, Ontario Dept. Mines, Ann. Rept., vol. 38, pt. 6 (1929) p. 1-58.

[30] A. L. Parsons: *Mineral developments in northwestern Ontario*, Ontario Bur. Mines, Ann. Rept., vol. 27, pt. 1 (1918) p. 178, 180-181.

[31] A. C. Lawson: *The correlation of the pre-Cambrian rocks of the region of the Great Lakes*, Univ. Calif., Dept. Geol., Bull., vol. 10 (1916) p. 15.

F. F. Grout: *Ages and differentiation series of the batholiths near the Minnesota-Ontario boundary*, Geol. Soc. Am., Bull., vol. 40 (1929) p. 806-809.

[32] F. F. Grout: *The Vermilion batholith of Minnesota*, Jour. Geol., vol. 33 (1925) p. 467-487.

I. S. Cram: *The Rest Island granite of Minnesota and Ontario*, Jour. Geol., vol. 40 (1932) p. 270-278.

A. C. Lawson: *op. cit.*, p. 82-103.

[33] A. C. Lawson: *Notes on some diabase dikes of the Rainy Lake region*, Canada Min. Inst., Pr., 1887 (1888) p. 173-185.

Block Creek area.—The volcanic schists, "Keewatin", and younger mica schist of Seine age can be traced eastward along the Seine River to Lac des Mille Lacs, where they disappear into the granite. However, Jolliffe reports similar formations some 30 miles farther east, in the Block Creek district, where they apparently reappear (Fig. 1). Here, the oldest

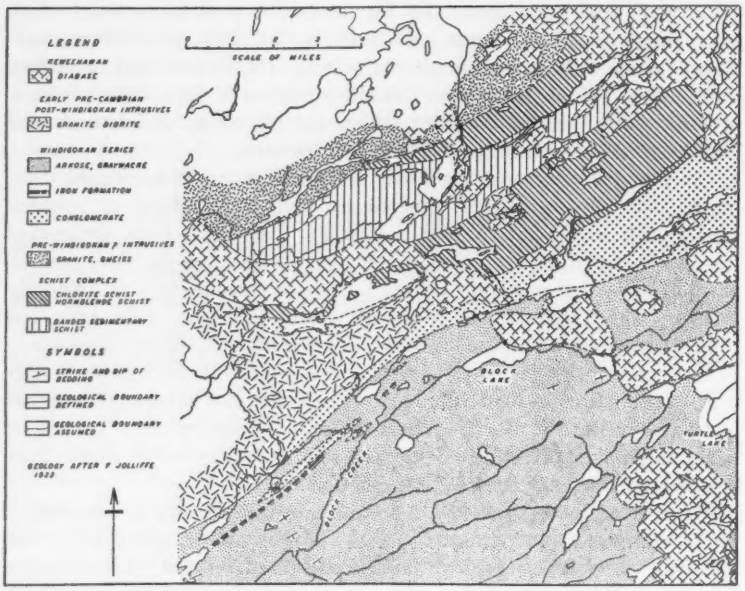

FIGURE 1.—*Geology of a portion of the Block Creek district*

geologic unit is a sedimentary-volcanic schist complex, the greater part of which consists of highly altered extrusives, the approximate equivalent of the "Keewatin" of the Seine River area. North of these rocks lies a granite batholith, classified as Laurentian, for pebbles of this granite are found in a great conglomerate formation, which is itself cut by granite (Algoman). This conglomerate, 3000 feet thick, carries detritus from the greenstone complex as well as from that of the granite, and is overlain by a little andesite, some silicified tuffs, iron formation, and a great thickness of slate and graywacke, which are locally converted into biotite schists by the younger batholithic intrusives. Keweenawan sediments and diabase (dikes and Nipigon diabase sheet) are the youngest bedrock formations.

The east-west-trending contact, just described, is more than 200

miles long, from Coutchiching Rapids on the Rainy River to Block Creek. Except for the gap east of Lac des Mille Lacs, the contact is uninterrupted. This line separates older volcanics ("Keewatin") and an older (Laurentian) gneiss (Shoal Lake, Steeprock Lake, and Block Creek) on the north from the Seine series on the south. Although the contact is locally marked by faulting, it is, in many places, characterized by thick conglomerates (Rat Root Bay, Niel Point, Cliff Lake, Shoal Lake, Pike Lake, Perch Lake, Jackfish Lake, Atikokan River, and Block Creek). It would indeed be peculiar if the Seine conglomerate should appear, as it does, in nine important places between the "Keewatin" on the one hand and the "Coutchiching" and almost nowhere else, unless the "Coutchiching" is in reality younger strata of Seine age. Locally (Shoal Lake), the conglomerate is repeated by folding. The evidence seems conclusive that the sedimentary series is superimposed on the volcanics except perhaps in the Rice Bay and the Bears Pass areas on Rainy Lake, where mica schist belts are north of the main contact. South of the Seine-"Keewatin" boundary are large masses of batholithic granite, which have replaced the sedimentary formations, in places invading the "Keewatin" itself and blotting out the boundary between sediments and lavas. South of Rainy Lake, Grout [34] has carried the correlation across to the Vermilion Range area in Minnesota. Throughout the Vermilion batholith are many mica schist inclusions and roof-pendant-like masses of mica schist and paragneiss. These schist areas within the granite have been assigned the same age as that of the main schist areas on each side of the granite, namely, Seine or Knife Lake. In all probability, therefore, these two series are identical in age.

STEEPROCK SERIES

One problem of importance remains unsolved—namely, the age and relations of the Steeprock series. Smyth, in 1891, described this series of conglomerates, limestones, and altered volcanics that apparently lies in a northwest-striking crumpled syncline, terminated on the south by a fault. The Steeprock series is separated from the Seine series. Lawson [35] placed the Steeprock unconformably below, whereas Tanton [36] has correlated the Seine conglomerate with the Falls Bay conglomerate of the Steeprock series. Merritt "attempted to trace the conglomerate which crops out along the Atikokan River into the Falls Bay conglomerate of the Steeprock series. . . . All attempts made in the field to establish the identity of the two conglomerates were unsuccessful," contrary to Tanton's correlation. The evidence of a pre-Seine age for the Steeprock series is,

[34] F. F. Grout: *Coutchiching problem*, Geol. Soc. Am., Bull., vol. 36 (1925) p. 354-355.

[35] A. C. Lawson: *The geology of Steeprock Lake, Ontario*, Canada Dept. Mines, Geol. Surv. Canada, Mem. 28 (1912) p. 10.

[36] T. L. Tanton: *Recognition of the Coutchiching near Steeprock Lake, Ontario*, Royal Soc. Canada, Tr., 3d ser., vol. 20, sec. 4 (1926) p. 48.

however, strong. The series has a notably different lithology from that of the nearby Seine series. Unlike the Seine, it contains limestones and abundant lavas. Moreover, it strikes northwest and, in spite of Hawley's attempt to harmonize the two,[37] appears unrelated to the structures that involve the Seine sediments. The Steeprock series is, moreover, intruded by gabbros that do not cut the Seine strata.

Leith,[38] in his most recent summary of the geology of the series, writes that the "two series were formed under different environments and are probably not of the same age, but faults obscure the true relations, and it is not yet possible to reach final conclusions as to their relative ages."

MANITOU SERIES

General statement.—On Pipestone, Manitou, and Stormy lakes is a series of sediments, which Thomson called the Manitou series.[39] The conglomerate of this series was noted as early as 1895 by Coleman,[40] on Mosher Bay of Manitou Lake, but an adequate description of the associated sediments was not made until 1934. On the Kenora sheet, Tanton showed the sediments of Stormy Lake to be Coutchiching and he did not differentiate those of Manitou Lake.

The Manitou series is represented by granite-pebble-bearing conglomerates, arkose, quartzite, slate, and a little agglomerate and tuff. Six separate areas, more or less in line, have been mapped by Thomson.

Pipestone Lake area.—Westernmost of these areas is that on Schistose Lake. In 1934, Burwash, on his map of the Kakagi Lake area, shows the sediments of this lake to be Keewatin. Little is known of the structure of this belt. Thomson[41] regarded it as a "closely folded, canoe-shaped syncline." One outcrop of conglomerate, carrying a few granite pebbles, is found on the southwest side of the structure.

The Schistose Lake belt of sediments extends southeastward to Pipestone Lake, though a short gap separates this belt from a second band, found on Thomson Bay of the some lake. At the latter place the sediments, mainly

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[37] J. E. Hawley: *Geology of the Sapawe Lake area, with notes on some iron and gold deposits of Rainy River district*, Ontario Dept. Mines, Ann. Rept., vol. 38, pt. 6 (1929) p. 28-29.

J. E. Gill: *"Seine" or "Coutchiching"* (discussion), Jour. Geol., vol. 39 (1931) p. 655-669.

[38] C. K. Leith, R. J. Lund, and Andrew Leith: *Pre-Cambrian rocks of the Lake Superior region*, U. S. Geol. Surv., Prof. Pap. 184 (1935) p. 16.

[39] J. E. Thomson: *Geology of the Manitou-Stormy lakes area*, Ontario Dept. Mines, Ann. Rept., vol. 42, pt. 4 (1933) p. 1-40; *Geology of the Straw-Manitou lakes area*, Ontario Dept. Mines, Ann. Rept., vol. 43, pt. 4 (1934) p. 1-32; *Geology of the Rowan-Straw lakes area*, Ontario Dept. Mines, Ann. Rept., vol. 44, pt. 4 (1936) p. 1-28.

In the second report, Thomson drops the name "Manitou series" in favor of "Timiskaming" on the ground that the sediments have been traced beyond the confines of the Manitou country and that the term Timiskaming is sufficient to locate their position in the stratigraphic column.

[40] A. P. Coleman: *Clastic Huronian rocks of western Ontario*, Geol. Soc. Am., Bull., vol. 9 (1898) p. 226-227.

[41] J. E. Thomson: *Geology of the Rowan-Straw lakes area*, Ontario Dept. Mines, vol. 44, pt. 4 (1936) p. 16.

arkose, quartzite, and slate, are described by Thomson as forming a double syncline. This interpretation is based on determinations of top and bottom of the beds, as shown by graded bedding.[42] The northern margin of the structure is believed to be in part marked by a fault, making it difficult to determine the relation of the sediments to the volcanics north of the belt. Of the eleven determinations of top and bottom shown by Thomson, only one lies on such a position as to suggest a superimposition of the sediments on the volcanics that lie north of the supposed syncline, and, as the fault marking the northern limit of the structure may well extend to this point, such superposition is hardly proved. A synclinal structure would require repetition of the acid volcanics of Straw Lake south of the supposed synclinal axis. Actually, they do not reappear. When the relations shown by the Esox belt of sediments, as well as those on Manitou and Stormy lakes, are also considered, it seems probable that, instead of "infolded synclines", these belts of Manitou sediments are homoclinal in structure and lie between two major volcanic series.

Esox Lake area.—The Manitou series, or its equivalent, is also found several miles to the east on Esox Lake, and on the adjacent lowermost part of Manitou Lake, where conglomerate, arkose, quartzite, and slate are found, and also in a small belt (arkose and slate) just west of Kahabness Lake, as shown by Thomson in his report on the geology of the Straw-Manitou lakes area. These two belts of "Timiskaming", together with the sediments of Pipestone Lake, are believed by Thomson to be canoe-shaped synclinal remnants of a once-continuous band of sedimentary rocks. On Esox Lake the sediments have an eastward strike and are in contact with older lavas on the south; in places, a granite-pebble-bearing conglomerate lies between the two. The Esox Lake stock of granite (with some quartz porphyry facies) intrudes both sediments and lavas. The beds have tops facing north (seven out of eight determinations) and are bounded on the north by basic volcanics. Thomson believes that a fault separates the sediments and these volcanics and that the lavas are also pre-sedimentary. Thus, the structure is a faulted syncline. The evidence for faulting is found, according to Thomson, on two small islands in Manitou Lake, where "well-stratified sediments strike N 40° W, yet directly along the strike on the adjoining mainland massive basic lavas are found. This situation can only be explained by a fault." An unconformity between younger lavas on the north might also explain the situation. Even if a fault be assumed, it is not yet proved that the lavas north of the sediments are of the same age as those to the south. The writer, in a brief visit to this area in 1935, found one outcrop (north shore of Manitou

[42] *Op. cit.*, fig. 2.

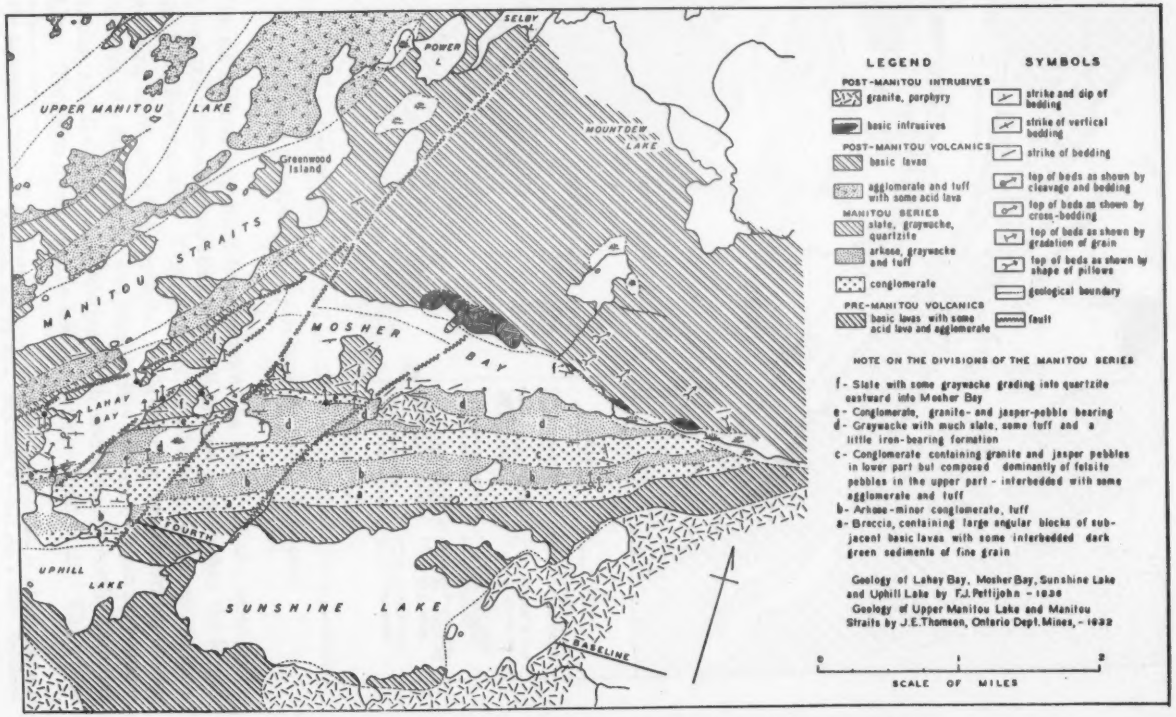
Stretch) in which the pillow structure showed the lavas north of the sediments to have north-facing tops. This indicates, if the contact with the sediments be not a fault, that the lavas are post-sedimentary.

Manitou (Mosher Bay) area.—On Mosher Bay and Manitou Straits of Manitou Lake is a large and more important belt of sediments. The structure here has been much more fully worked out [43] (Pl. 2). According to Thomson's interpretation, the conglomerates of the Manitou series (with some minor agglomerate) rest unconformably on "Keewatin" lavas, and are conformably overlain by arkose, slates, and graywackes. The whole series is sharply folded, faulted, and intruded by quartz porphyry and granite. The structure is believed to be a syncline, bounded in part by a major fault on the northwest side, for which there is considerable evidence. However, in the easternmost part of Mosher Bay, where no faulting is postulated, the sequence from south to north across the near-vertical strata is (1) basic lavas, intruded by granite (Sunshine Lake); (2) Manitou sediments (with minor agglomerate), with eastward strike; consisting of six mappable subdivisions, top-facing north (20 out of 23 observations); and (3) basic lavas cut by basic intrusives and quartz porphyry dikes. The actual contact of No. 2 and No. 3 is largely covered by the waters of Mosher Bay. The sequence of members is not repeated as required by synclinal theory of structure; a top north orientation prevails in the sediments; and the northern boundary, fairly closely located, apparently transgresses the sedimentary bedding so that the basic volcanics of the north rest in different places on different members of the Manitou series, or on the lower volcanics. In 1936, the writer made a study of this section. He found pillow structures in the spherulitic lavas just north of the east end of Mosher Bay, which indicated that these strata, like the sediments, have north-facing tops and are, therefore, superimposed on the Manitou series (Pl. 2).

Stormy Lake area.—The easternmost belt of sediments is that of Stormy Lake, where the beds have a northwest strike (Fig. 2). This belt is interpreted by Thomson to be a syncline, apparently largely on evidence afforded by direction of dip, though Thomson notes that this criterion is not wholly reliable. The beds are intruded by both quartz porphyry and granite. Associated lavas are mapped as Keewatin.

In a brief survey in 1935, the writer found graded bedding in the arkosites and slates about 400 feet from the northeastern contact of the sediments with the volcanics, indicating that the tops of the sediments are northeast-facing, and thus proving them to be below the greenstones and green schists (Fig. 2).

[43] J. E. Thomson: *Geology of the Manitou-Stormy lakes area*, Ontario Dept. Mines, Ann. Rept., vol. 42, pt. 4 (1933) fig. 2.


SELBY L.
POWER L.
UPPER MANITOU LAKE
Greenwood Island
MOUNTDEW LAKE
MANITOU STRAITS
MOSHER BAY
LAHAY BAY
FOURTH
UPHILL LAKE
SUNSHINE LAKE
BASELINE
LEGEND
SYMBOLS
POST-MANITOU INTRUSIVES
granite, porphyry
basic intrusives
POST-MANITOU VOLCANICS
basic lavas
agglomerate and tuff with some acid lava
MANITOU SERIES
slate, graywacke, quartzite
arkose, graywacke and tuff
conglomerate
PRE-MANITOU VOLCANICS
basic lavas with some acid lava and agglomerate
strike and dip of bedding
strike of vertical bedding
strike of bedding
top of beds as shown by cleavage and bedding
top of beds as shown by cross-bedding
top of beds as shown by gradation of grain
top of beds as shown by shape of pillows
geological boundary
fault
NOTE ON THE DIVISIONS OF THE MANITOU SERIES
f- Slate with some graywacke grading into quartzite eastward into Mosher Bay
e- Conglomerate, granite- and jasper-pebble bearing
d- Graywacke with much slate, some tuff and a little iron-bearing formation
c- Conglomerate containing granite and jasper pebbles in lower part but composed dominantly of felsite pebbles in the upper part - interbedded with some agglomerate and tuff
b- Arkose-minor conglomerate, tuff
a- Breccia, containing large angular blocks of subjacent basic lavas with some interbedded dark green sediments of fine grain
Geology of Lahay Bay, Mosher Bay, Sunshine Lake and Uphill Lake by F.J. Pettijohn - 1936
Geology of Upper Manitou Lake and Manitou Straits by J.E. Thomson, Ontario Dept. Mines, - 1932
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1
2
SCALE OF MILES

GEOLOGY OF MOSHER BAY (MANITOU LAKE) AND VICINITY

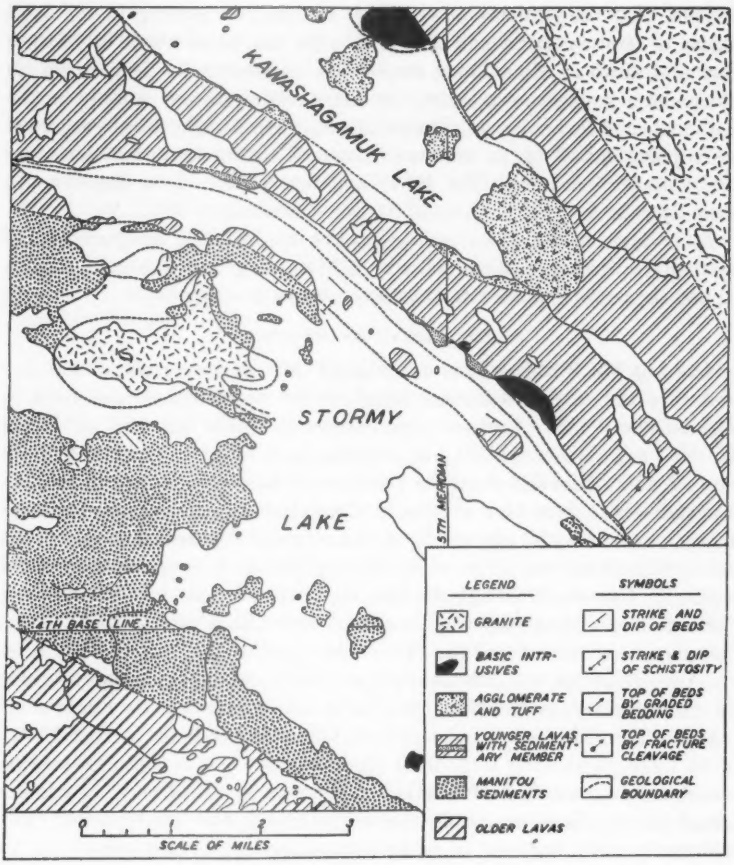


FIGURE 2.—*Geology of a portion of the Stormy Lake area*

The six sedimentary belts thus reviewed lie nearly on the same strike line, and the intervals separating the belts are not greater than the length of the belts themselves.[44] The two belts with best known structure have tops facing north and have granite-pebble-bearing conglomerates on the south sides; the Stormy Lake and Mosher Bay belt are overlain by younger volcanics, and the Esox Lake belt may be bounded on the north in similar fashion. Thomson interprets the belts as synclinal remnants. The writer

[44] The approximate lengths of the several belts and the intervals between are as follows: Schistose Lake belt, 4 miles; gap 3 miles; Pipestone, gap 2½ miles; Esox belt, 7 miles; gap 5 miles; Kahabness belt, 1 mile; gap 10 miles; Mosher Bay belt, 13 miles; gap 5 miles; Stormy Lake belt, 14+ miles.

believes that the evidence afforded by the graded bedding in the sediments of Stormy Lake and the pillows in the lavas north of Mosher Bay and north of Esox Lake, shows that the sediments lie between an older and a younger lava series, the latter resting unconformably on the sediments and earlier lavas. The sedimentary belts might thus be regarded as cropping out along the southern margin of a great basin between older and younger volcanics. The latter apparently differ from the older in the extraordinary development of pyroclastic facies.

Both series of volcanics and sediments are intruded by granites and related porphyries. No undoubted pre-Manitou granites capable of supplying the granite cobbles in the conglomerates are reported.

WARCLUB-ABRAM-SAVANT SERIES

Lake of the Woods.—It is exceedingly difficult to correlate with any certainty the various volcanics found on the many islands and bays of Lake of the Woods. Lawson's original description of this area, published in 1885, is a classic, and his mapping has been found to be substantially correct. Van Hise and the other members of the International Committee concluded that there were no structural breaks between the various classes of materials, mainly agglomerates and ellipsoidal greenstones, and that these "constitute one series which is very largely igneous or volcanic in origin." Parsons,[45] though making minor corrections in the mapping, differed in no important way from the conclusions of Lawson. Greer, however, in a re-study of the Shoal Lake portion, divided the volcanics into two divisions, one dominantly basic lavas and the other mainly basic lavas with much interbedded pyroclastic material and a few minor sediments. The latter are found on Royal Island, Spike Point, and on Crowduck Lake. The latter is the most significant, for here is a granite-bearing conglomerate, nearly half a mile in thickness at its place of maximum development. Boulders more than a foot in diameter are reported. The belt is 6½ miles long and is cut by felsites and quartz porphyry.

Structural studies based on orientations determined by a study of the pillow structures in the lavas show a thickness of from 4 to 5 miles for the lavas. The structural attitude of the Crowduck Lake conglomerate is not given. It is possibly reappearance of a similar series found many miles farther east, on Abram and Savant lakes. It is impossible, without further field study, to trace any certain connection between this formation and the Abram Lake sediments.

Suffel re-mapped the Bigstone Bay section of the Lake of the Woods. He divided the volcanics into two series, one mainly basic volcanics and

[45] A. L. Parsons: *Gold fields of Lake of the Woods, Manitou and Dryden*, Ontario Bur. Mines, Ann. Rept., vol. 20, pt. 1 (1911) p. 158-178.

the other acid flows and agglomerates. In the vicinity of Andy Lake, a series of "gneissoid biotite schists", possibly of sedimentary origin, is differentiated from the normal greenstone assemblage. A few "tuffaceous (?) sediments" are reported from four localities near the contact of the acid and the basic members of the volcanic complex.

Granites, both in stock-like masses and in larger batholithic bodies, are common in the Lake of the Woods territory. Suffel calls them Laurentian; Greer designated them as Algoman; Burwash classed some as Algoman, but most of them as Laurentian; and Thomson, in the Straw-Rowan lakes section, called all the granitic rocks Algoman. There are apparently no good criteria for discrimination between the granites of these two periods.

Lobstick Bay, Lake of the Woods.—On Lobstick Bay of Lake of the Woods is a sedimentary series, which Burwash, in his Kakagi Lake report, called the Warclub series. Lawson originally mapped "hydromicaceous schists" and included them in Keewatin in his 1885 report. In the Manitou Lake sheet McInnes extended the limits of these rocks eastward beyond Lawson's map area. Tanton, in the Kenora sheet, after a brief visit to the area, mapped them as Coutchiching. Burwash, the only one to report on these beds in any detail, believed them to be Coutchiching. They are prevailingly of clastic character, though Burwash thinks that they are mainly volcanic ash with a few interstratified sedimentary rocks derived from weathering. Burwash placed these beds below the lowest member of the "Keewatin", as described in his report, because they apparently dipped away from the dome-like mass of Kishquabik granite (regarded as Laurentian) and beneath flanking volcanics. A "rhyolitic formation" is reported to be below the sediments.[46]

The overlying volcanics are marked in this area by the great abundance of pyroclastic materials. All the aforementioned rocks are cut by basic intrusives (diorite, amphibolite, and others), a younger series of granite (Algoman), and post-granite diorite dikes (Keweenawan). The distinction between the so-called "Laurentian" and the "Algoman," made by Burwash, seems open to some question. Burwash says that the two can be differentiated by the manner in which the material has been intruded. The older granite, usually more gneissoid, according to Burwash, has intruded the Keewatin lavas "by filling large dome-like anticlinal folds

[46] T. L. Tanton: *personal communication* (1935). "The sediments on Lobstick Bay were classed as Coutchiching as a result of personal examination (assisted by F. T. Jolliffe) along a part of the contact as shown. A study of the texture gradations in bed, in outcrops adjacent to the greenstone, showed tops toward the greenstone. The sediments in that area have been felsitized and otherwise altered near the granite contact. I think that the felsites and felsitized sediments might reasonably be grouped with the intrusives if one were mapping in detail, but not as lavas, as would follow if one (erroneously) identified them as rhyolites."

from below, rather than penetration of the rock" as is characteristic of the younger granites. The latter are said to occupy synclinal troughs.

Thunder and Eagle lakes belt.—About 25 miles northeast of Lobstick Bay, on Eagle Lake, are sediments, largely fine paragneiss and mica schists, with development of garnet and staurolite, which extend from this point eastward to Wabigoon, Sandybeach, and Minnitaki lakes, a distance of about 75 miles. Parsons [47] describes the iron formation associated with these schists near Dryden, Thunder Lake, and Eagle River station. This phase is probably a westward continuation of the formation that occurs so persistently near the southern boundary of the Minnitaki Lake sediments. Thomson, in a study published in 1917, gives a more complete description of the character of these altered sediments and volcanics, but does not present any evidence to show their relative ages. He classes both of them as "Keewatin" and calls the sediments "a border phase of the Keewatin", though admitting the very different petrographic character and origin of the latter. Wright briefly mentions these formations in a report on talc deposits published in 1926. He calls both of them "Keewatin", and places the sediments below the lavas because of the general southward dip and the areal distribution of the sediments. On the Kenora sheet, Tanton classed the mica schists as Coutchiching. No conglomerate is reported, and at one place the contact, according to Thomson, is marked by an acid porphyritic rock (quartz porphyry or dacite). A survey of Thunder Lake in 1935 (Fig. 3) demonstrated that the sediments, mainly mica schists and iron formation with much interleaved granite, apparently form a gentle anticline with westward pitch. Hornblende schists, interpreted as an earlier volcanic series, crop out along the northeast shore of the lake along the axial region. These are, in turn, flanked by the low-dipping meta-sedimentary rocks that crop out on the north, west, and south shores of the lake. South of the sedimentary schists, on Wabigoon Lake, is a younger volcanic series—greenstones, green schists, and agglomerates. The age relations are, therefore, determined by the general areal relations controlled by the anticlinal structure. No good data on structural orientation of the beds were obtained, though on the islands just west of the peninsula near the outlet to the lake, graded bedding indicated the top of the beds to be south-facing, confirming the sequence as here interpreted.

Minnitaki Lake area.—The sediments of Eagle, Wabigoon, and Thunder lakes are apparently directly connected with those of Minnitaki Lake.

Hurst, in his report on the geology of the Sioux Lookout region, described interbedding of "Keewatin" lavas and sediments and concluded,

[47] A. L. Parsons: *op. cit.*, p. 194-196.

therefore, that no great time interval had elapsed between the "Keewatin" and the "Timiskaming." The writer's re-examination of the Red Pine Bay portion of Minnitaki Lake in 1936 proved the apparent interbedded

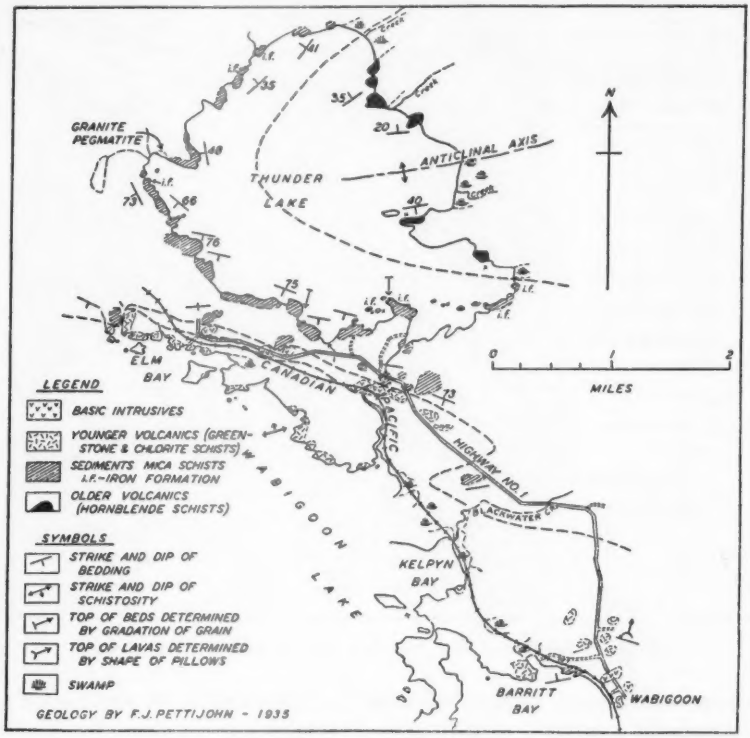


FIGURE 3.—*Geology of Thunder Lake area*

relations to be due in part to intrusive sill-like masses of basic rocks related to gabbro and diorite. The volcanics (both flows and interbedded tuffs) have their respective tops facing north; the sediments have their tops facing south (Fig. 4). Hence, the contact between the lavas and the sediments is a fault, and the age relations of the two series remains unknown. Confirmatory evidence of the boundary fault is the oblique cross-cutting relations of the contact to the strike of certain peculiar basalt porphyry flows in the volcanic series (Fig. 4). However, conclusive evidence of a pre-sedimentary lava series is obtained on Red Pine Bay itself. The greenstone on the northwest shore of this bay lies along an

anticlinal axis, with the flanking sediments so oriented as to prove this relation. On the other hand, the volcanics between Pickerel Arm and the

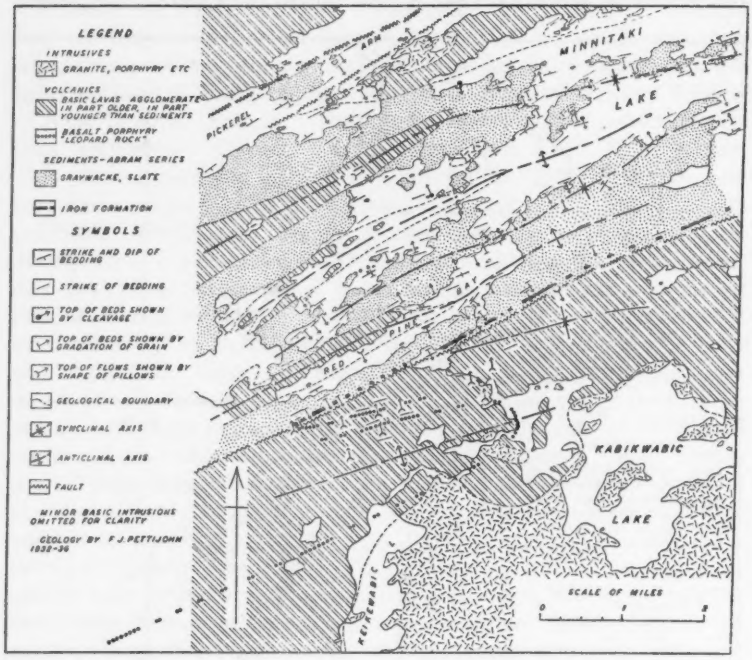


FIGURE 4.—*Geology of Red Pine Bay (Minnitaki Lake) and vicinity*

most southwesterly part of Minnitaki Lake apparently lie along a synclinal axis.

The section on East Bay of Minnitaki Lake is, however, more informative (Pl. 3). The sequence here, re-studied in 1935 and 1936, is (1) older volcanics ("Keewatin") and pre-Abram quartz porphyry; (2) East Bay formation (quartz porphyry- and granite-bearing conglomerates and interbedded white arkosites); (3) Phantom Island varved slates and interbedded graywacke (which were the subject of a paper published in the BULLETIN earlier this year); (4) Mackenzie Island graywackes and slate; (5) younger volcanics, mainly andesite porphyries with many interbedded tuffs and agglomerates. The younger volcanic series, called the Neepawa volcanics, apparently lies unconformably on the earlier volcanics and sediments. Basic intrusives cut the sediments and earlier volcanics. Strong faulting complicates the structure here, as on Manitou Lake.

GEOLOGY OF EAST BAY (MINNITAKI LAKE) AND VICINITY

The sediments of Minnitaki Lake are everywhere separated from a parallel belt of sediments on Abram and Vermilion lakes, by greenstones, from 2½ to 5 miles wide. Everyone who has worked on these two sedimentary bands [48] regards them as of the same age and has regarded the greenstones separating them, and lying both to the north of one and to the south of the other, as older than the sediments, or as Keewatin in age. The writer noted [49] that the structural orientation of the beds themselves in many places contradicted this assumption. He, therefore, postulated faulting to explain the anomalies. A re-study of Vermilion Township, which the writer published in 1935, confirmed earlier interpretations, though within that area, the existence of volcanics (tuffs) younger than the conglomerates was proved.

The volcanics lying between, and separating, the Abram Lake sediments from the sediments of Minnitaki Lake are, as a result of these newer studies, thus interpreted as belonging to a post-sedimentary volcanic series. These materials occupy the whole of Northeast, Troutfish, and Lyons bays of Minnitaki Lake. The lavas that lie north of the sediments of Abram Lake, in Block 10, and the lavas that lie south of the sediments of East Bay are interpreted as pre-sedimentary in age. The evidence for the relations on East Bay was given in a paper by the writer, published in 1936. Petrographically, the younger volcanics are marked especially by a large quantity of agglomerate and tuff, massive lavas markedly porphyritic—mainly andesite and dacite porphyries—and absence of iron formation and of "basalt porphyry" or "leopard rock." Both acid and basic intrusives cut both the sediments and the volcanics.

Vermilion and Abram lakes belt.—The sediments that extend from Abram Lake to the Vermilion Lake area constitute an important band of stratified rocks. In Vermilion Township, where the most nearly complete section has been worked out, are thick arkosites and granite-pebble-bearing conglomerates, in the main with tops facing south, resting unconformably against a thick (10,000 feet) section of lavas, agglomerates, and sediments (Patara).[50] Above the conglomerate-arkosite formation (Ament Bay formation) are acid and basic tuffs, and varve-like slates and graywackes (Daredevil formation). The sediments (Abram series)

[48] W. H. Collins: *A geological reconnaissance of the region traversed by the National Transcontinental Railway between Lake Nipigon and Clay Lake, Ontario*, Canada Dept. Mines, Geol. Surv. Canada, Pub. no. 1059 (1909) p. 25.

M. E. Hurst: *Geology of the Sioux Lookout area*, Ontario Dept. Mines, Ann. Rept., vol. 41, pt. 6 (1933) p. 1-33.

F. J. Pettijohn: *Conglomerate of Abram Lake, Ontario, and its extension*, Geol. Soc. Am., Bull., vol. 45 (1934) p. 497-498.

[49] F. J. Pettijohn: *op. cit.*, p. 498, and Pl. 51.

[50] An intra-Keewatin series (about 1500 feet thick).

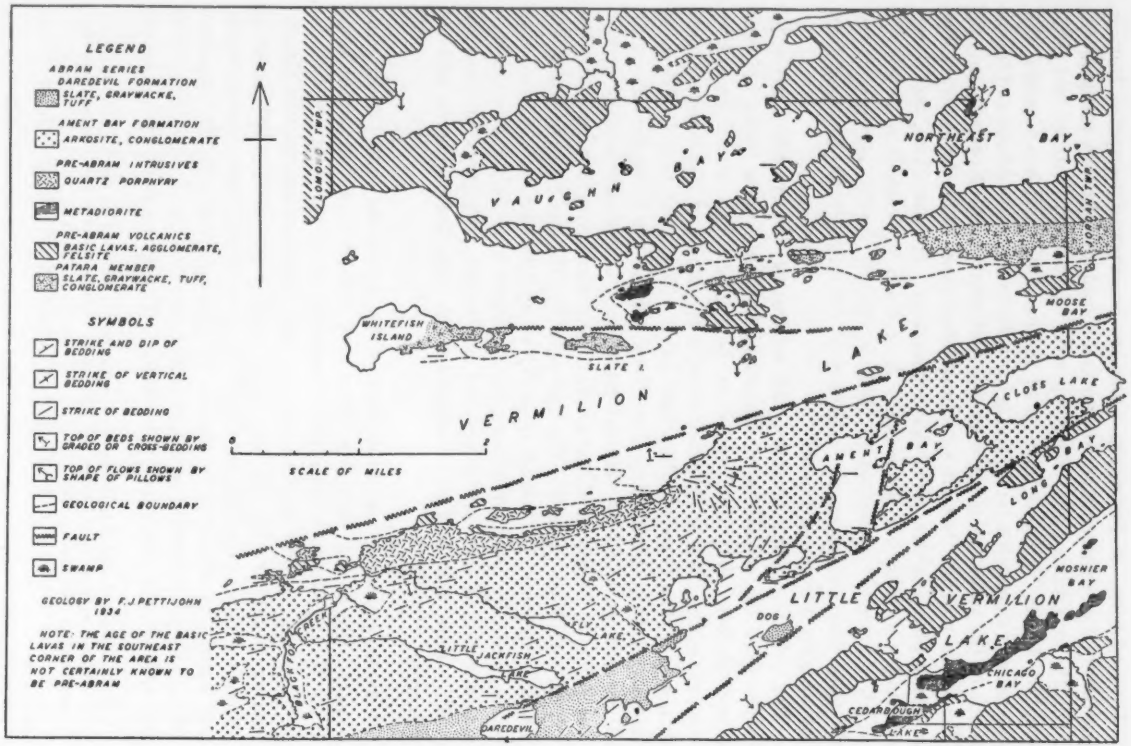


FIGURE 5.—*Geology of Vermilion Township*

are at least 9000 feet thick. The structure is much complicated by faulting, but the orientation of the older lavas and sediments is, almost without exception, with tops facing south (two exceptions in forty-seven determinations in Vermilion Township). The sedimentary belt widens southwestward but is ultimately lost in a granite area (Fig. 5).

The sedimentary belt, mainly coarse conglomerate, extends eastward to Abram Lake, the type locality for the Abram series.[51] Here, the conglomerate lies between volcanics, which lie south of the conglomerate band, and sediments and interbedded tuffs, which lie to the north. It was supposed that the conglomerate was basal to the sedimentary strata, but in 1935 the pillow lavas just south of the contact with the conglomerate were found to be south-facing. The vertical conglomerate, likewise, may have a south-facing top, as some obscure cross-bedding seems to suggest. If so, the sediments north of the conglomerate are pre-Abram and perhaps Patara [52] in age; the volcanics, which lie south of it, are younger. Faulting, however, complicates the structure, and, until detailed work is done, the true relation will remain unknown.

In Block 10, just east of Sioux Lookout, is a conglomerate charged with granite cobbles and somewhat recrystallized and squeezed. North of the conglomerate lie the hornblende schists ("Keewatin") and south of it lie arkosites, graywackes, phyllites, and iron-bearing formation. This conglomerate has been correlated with the Abram Lake conglomerate.

The similarity of strike, dip, lithology, sequence, and structural orientation (top south) leaves little doubt as to the identity of the conglomerate in Block 10 and that on the Marchington River. A gap of 22 miles separates the known outcrops of the two formations. Certain structural and physiographic features of the intervening territory led to the conclusion that faulting and batholithic intrusion severed the Block 10 and the Marchington River band of conglomerate.

Marchington River.—The conglomerates of Marchington River can be followed, without significant break, eastward from Schist Lake to Savant Lake. North of the conglomerate band are the volcanic green schists, and south of it are arkosic schists, in places interbedded with green schists (tuffs?). The top is apparently to the south. Locally, between Schist and Fairchild lakes, a younger granite interrupts the continuity of the formation. The conglomerate of Schist Lake is much squeezed, much recrystallized, and granitized by the batholithic mass on the north.

Savant Lake area.—The first report on the Savant Lake area as a unit was made by Moore in 1910. In 1928, he made a re-study of the area,

[51] F. J. Pettijohn: *Conglomerate of Abram Lake, Ontario, and its extensions*, Geol. Soc. Am., Bull., vol. 45 (1934) p. 479-506.

[52] *Op. cit.*, p. 483.

FIGURE 5.—*Geology of Vermilion Township*

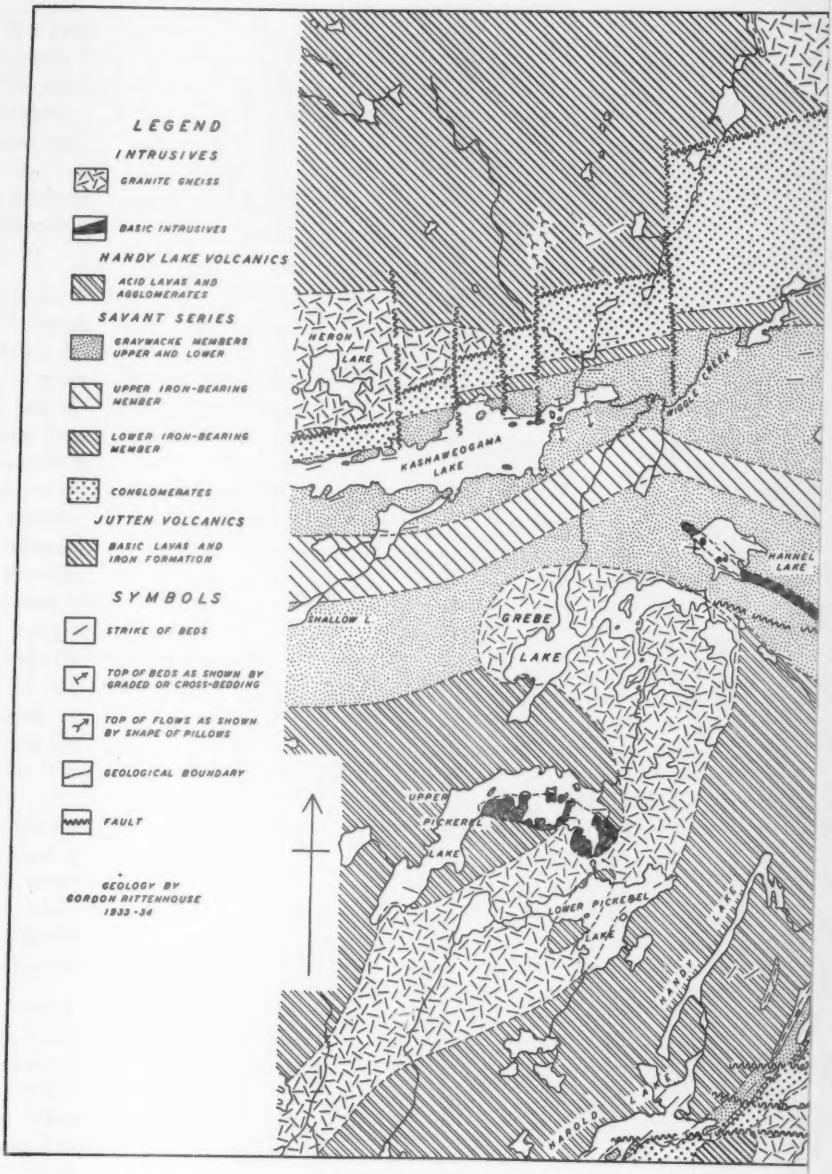
and, in 1936, Rittenhouse made a careful stratigraphic and structural survey of a part of the district (Pl. 4). The regional structure is interpreted by Moore, and confirmed by Rittenhouse, to be that of a great syncline with pitch to the southwest. This structure is marked by a wide "V" outcrop pattern, outlined by a thick and persistent conglomerate band (Pl. 1). The apex of the "V" is directed northeastward. The conglomerate marking one limb of the structure extends east and west along the Marchington River. At Kasheweogama Lake (Pl. 4) the sequence from north to south, across the steeply inclined north limb, is, according to Rittenhouse (1) pre-conglomerate volcanics (Jutten volcanics) (and granite porphyry ?); (2) conglomerate; and (3) graywacke and slate with iron formation. As the conglomerate beds have a south-facing orientation, the volcanics are older, and the iron formation and others are younger. The lavas, however, have north-facing tops; hence, faulting or pronounced angular unconformity separates the lavas and the sediments. A younger granite intrudes the conglomerate as well as the lavas. Considerable cross-faulting is reported.

The conglomerate marking the other limb of the great syncline is found in the vicinity of Savant Narrows, and southward (Pl. 4). Here, the sequence from southeast to northwest is, according to Rittenhouse (1) pre-conglomerate lavas (Jutten volcanics) intruded by a granite batholith; (2) conglomerate; (3) graywacke, slate, and iron formation; (4) acid volcanics, flows, and agglomerates. As only a few hundred feet of finer sediments lie between the upper volcanics and the conglomerate, in contrast to the thousands of feet of finer beds in the Marchington River section, possibly the younger lavas unconformably overlap the sediments. Within the syncline, along its axis, are intrusives of younger granite and some associated basic irruptives. The granite east of the South Arm band of conglomerate, however, may be pre-sedimentary in age.[53] The younger volcanics are marked by their acid character. As they crop out in typical fashion on Handy Lake, Rittenhouse called them the Handy Lake volcanics.

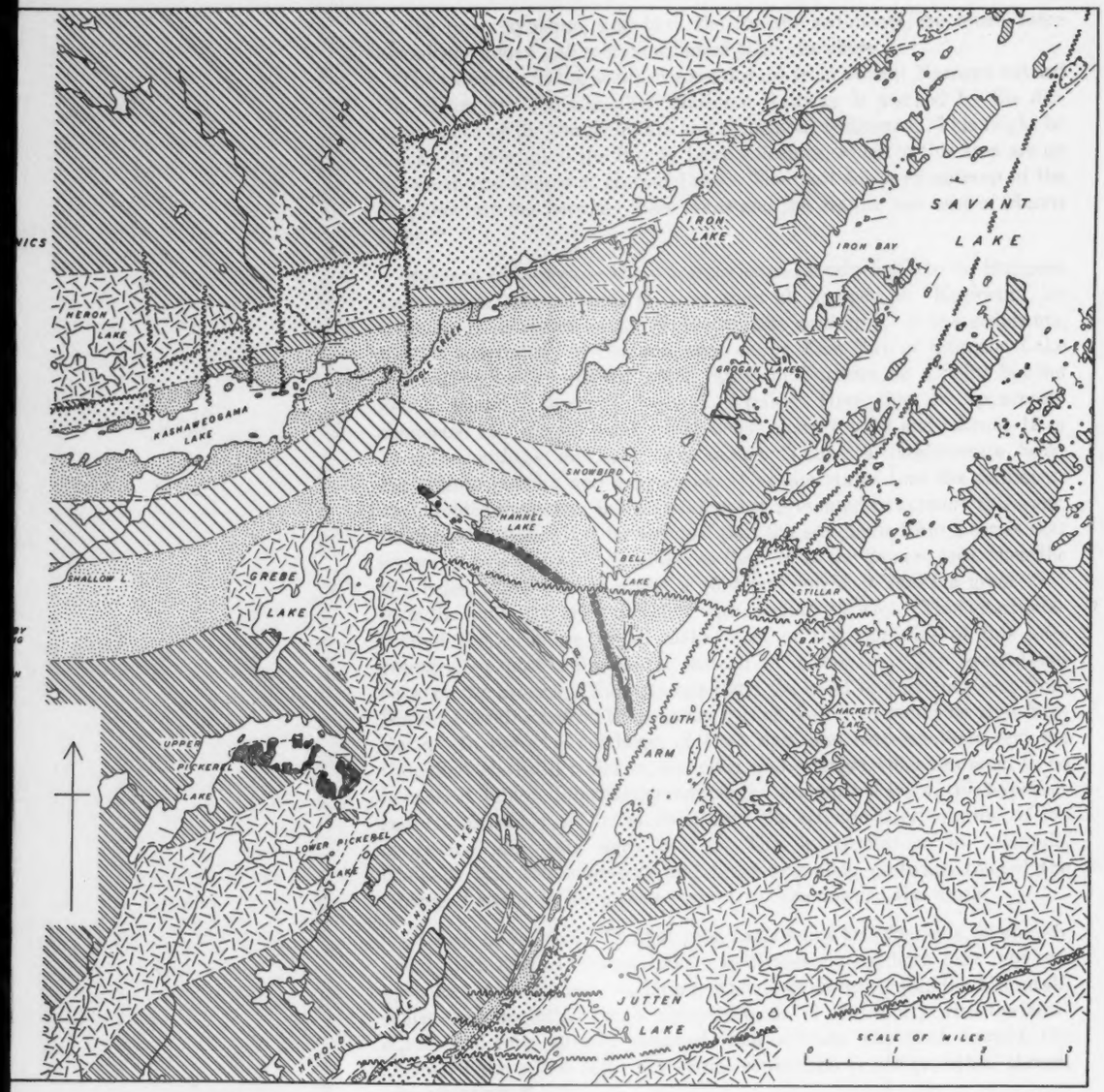
The conglomerate of the Savant area is marked by its great thickness and its persistence, for more than 56 miles along the Marchington River. The formation is, in places, a boulder conglomerate, containing both greenstones and granite, some boulders of which are more than 5 feet in diameter. The thickness north of Iron Lake is about 9000 feet, according to Rittenhouse, and Moore, in his 1928 report, estimated a thickness of 16,000 feet for the whole series.

Neverfreeze Lake, northwest of Savant Lake, seems to occupy the apex

[53] Gordon Rittenhouse: *Personal communication* (1935).



GEOLOGY OF A PORTION OF SAVAN



GEOLOGY OF A PORTION OF SAVANT LAKE AREA

of the great syncline, and here the Savant sediments are much more complexly folded and metamorphosed than elsewhere.

The extension of the sediments southward from Savant Narrows toward Chivelston and the Canadian National Railway is marked by the disappearance of the conglomerate and associated sediments. This might be due to the overlap of the Handy Lake volcanics, which in this area are on the northwest shores of Harold Lake. The most southern outcrop of the conglomerate lies between these lavas and the granite just east of Harris Lake.[54]

Sturgeon Lake area.—The volcanics extend southward into the Sturgeon Lake region, where, however, they were all mapped as "Keewatin" by Graham in his report on the Sturgeon Lake gold area. A few sediments, the "Timiskaming" of Graham, crop out at East Bay of Sturgeon Lake and extend southwestward, along Sturgeon Narrows, to a point beyond Seaton Island, a distance of about 12 miles. Here, they are apparently connected to a second band, which bends sharply back and extends 12 or 13 miles southeast and east. The sediments contain conglomerate, bearing granite pebbles and graywacke. Graham states that the sediments are infolded synclines, but no evidence is presented to support this view. On the other hand, if it be assumed that the sediments form a series that separates two series of volcanics, as they do in the Savant area, then the two belts, which join at about a 45-degree angle, to make a great "V", form the limbs of a great anticline with pitch to the west. This interpretation of the structure would make most of the volcanics of this area younger, or post-sedimentary, instead of Keewatin. The greenstones between the Sturgeon Narrows band and the band that extends east from Seaton Island—that is, those lavas within the "V"—would be true Keewatin. In the area northeast of East Bay, and between there and the Canadian National Railway, the older and younger volcanics seem to be in contact without intervening sediments. A simple check of this hypothesis of structure could be made if only the structural orientation of the lavas and sediments were known. This interpretation, for example, demands that the sediments and lavas extending eastward toward the Obonga Lake area have their respective tops toward the south.

Obonga Lake area.—The Sturgeon Lake schist belt connects, as already noted, with that of Savant Lake. It divides its southern part into two branches. One of these, the larger, extends westward to join the Minnitaki schist area; the other bends abruptly back, in conformity with the anticlinal structure already outlined, and extends eastward toward the Obonga Lake schist belt. An actual connection is not probable, though

[54] E. S. Moore apparently believes the conglomerate to be cut out by intrusion.

the size of the gap between them is not more than from 30 to 40 miles. Both sediments and volcanics are found in the Obonga Lake area. Of these, Kidd says:

> "The sediments occur with the volcanics as bands from a few feet wide to three-quarters of a mile wide. They comprise quartzite, grit arkose, slate and phyllite, greywacke, and conglomerate, the last often with abundant granite pebbles. The wider bands have considerable thickness of coarse conglomerate. . . . In no single band of sediments was there discovered any evidence of duplication of the strata in cross-section, such as would suggest tight infolding of the younger rocks in the volcanics. Some of the sedimentary bands towards their sides contain increasing amounts of greywacke and volcanics until the rocks are all volcanics. . . . It is concluded . . . that in the map area there are volcanics younger than some of the sedimentary bands holding conglomerates bearing granite pebbles."

Three bands of sediments are described. All dip steeply to the south, and in two of them the tops of the sediments were determined to be toward the south. The top of the lavas lying to the south of one sedimentary belt, the westernmost, indicated a top-south position. Elsewhere the top orientation was not determinable. The granites of the area are younger than volcanics and sediments. The flat-lying Nipigon diabase (Keweenawan) overlies in places all the earlier pre-Cambrian. The structural orientation (top-south) is exactly that required if the interpretation of the Sturgeon Lake area, as already given, is correct, and if a connection between them once existed, as seems highly probable.

In summary, sediments, resting on older volcanics in places and overlain by younger volcanics in other places, have been described from Lobstick Bay of Lake of the Woods to Obonga Lake, a distance of more than 200 miles in a direct line. The continuity of outcrop has been disturbed by batholithic intrusion and possibly by reason of overlap of the younger volcanics on the older.

The most conspicuous feature of the sediments along this line is the conglomerate, locally very thick, which is believed to be of terrestrial origin. Of note also are the varve-like alternations of slate and graywacke, the extensive iron formation in the Savant Lake area, and its extensions on Abram, Minnitaki, and Thunder lakes and Eagle River.

Volcanics are interbedded with the sediments in the Obonga Lake area and overlie the sediments in the Savant region and the Minnitaki Lake and Lobstick Bay districts. Such also seems to be the structure in the Wabigoon and Eagle lakes district and possibly in the Sturgeon Lake region.

Only two certainly pre-sedimentary intrusives are known—namely, the small quartz porphyry body of Vermilion Lake and the quartz porphyry southeast of East Bay of Minnitaki Lake—though possibly the Heron Lake stock of porphyritic granite and the Senseganaga gneiss of the

Savant and Sturgeon districts are older than the sediments. Very possibly, some of the gneiss between Lac Seul and Abram Lake is also pre-sedimentary.

Elsewhere, large batholithic masses have intruded both the sediments and the associated volcanics and have engulfed and destroyed much of the geologic record.

In the Sioux Lookout region—especially Vermilion Township—an earlier pre-Abram sedimentary series (the Patara series) is known. Possibly, also, the iron-bearing formation of Twinflower Bay of Minnitaki Lake lies below the main sedimentary series of that place.

RICE LAKE-MINISS SERIES

Rice Lake.—In 1913, Moore and, in 1922, Cooke described the geology of the Rice Lake area. Moore divided the schists of that area into an earlier Rice Lake series, mainly volcanics, and a later Wanipigow series, mainly sediments. Moore believed that the two were separated by an unconformity. Cooke, however, called the whole sequence Rice Lake series and divided the latter into two parts with conformable relations, the lower member being lavas and breccias and the upper tuffaceous sediments. In 1922, Wright dropped the local names and divided the rocks into three formations: (1) a volcanic series; (2) an overlying conformable sedimentary series; and (3) a sedimentary series of unknown relations. The next year, as a result of careful structural study, Wright reversed his former sequence and placed the principal sedimentary series at the base of the section, believing this to be overlain by an interbedded sedimentary and volcanic assemblage, in turn overlain by a purely volcanic series (Fig. 6). In 1932, he divided the Rice Lake series into three phases (reviving and redefining the names of Moore): (1) a lower sedimentary series (Manigotagan phase); (2) an overlying volcanic complex (Beresford Lake phase); and (3) a sedimentary series (Wanipigow). It was believed that the Wanipigow and Beresford Lake phases were "formed during the same period, and that their interfingered contact represents a rather sharp line between an area of dominant volcanic activity in shallow water to the west." Wright regards the Manigotagan phase as earlier than the Beresford Lake phase, though "the contact zone, wherein the rocks of the two groups appear intermixed, is interpreted as representing a transition stage from sedimentary conditions to essentially volcanic conditions." The sequence as stated by Wright was proved by careful structural work, which gave due consideration to the minor structural features, such as ripple markings, which indicated the position of top and bottom in the near-vertical sequence.

In 1924, Wright correlated the lavas of the Rice Lake area with the Keewatin of Lake of the Woods and Rainy Lake and the pre-lava

sediments (Manigotagan) with Lawson's Coutchiching of the Rainy Lake area. In 1932, he regarded the whole Rice Lake series as the equivalent of the Keewatin.

Oiseau River.—Wright has also studied the Oiseau River area in southeastern Manitoba, where correlatives of the Rice Lake series are known.

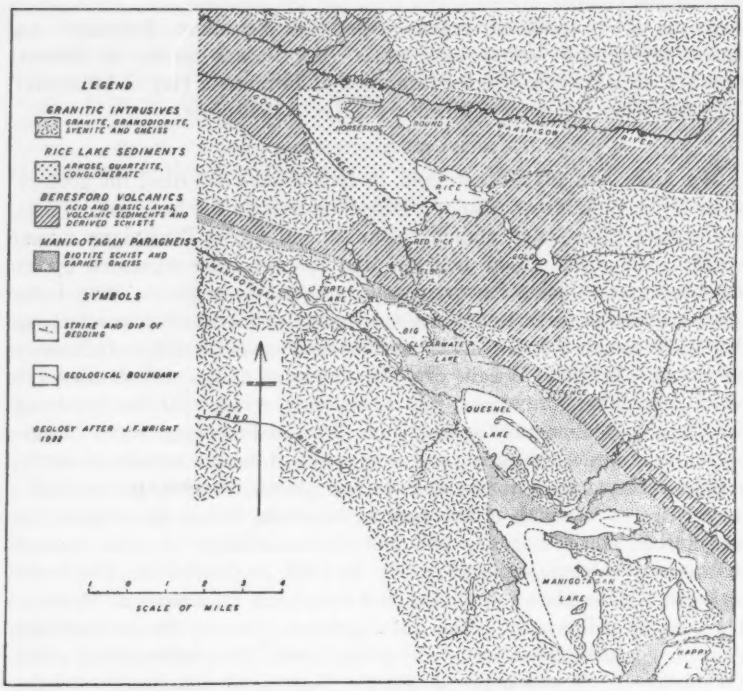


FIGURE 6.—*Geology of Rice Lake and vicinity*

In 1924, he found a large volume of sediments, principally mica schists, below a volcanic series (with minor sedimentary admixtures). The evidence of order of superposition is not so clear in this district as it is in the Rice Lake section. In general, it is based on the regional direction of dip.

In summary, it may be noted that in the Manitoba sections there is a pre-lava sedimentary series, now mainly graywacke, quartzite, slate, chert, and cherty quartzite and a little interbedded granite-pebble-bearing conglomerate and metamorphic equivalents (mica schist and paragneiss), estimated to be not less than 5400 feet thick in the Beresford-Rice

lakes area. This is overlain conformably by a volcanic series (Beresford Lake phase), containing both acid and basic lavas and their schist equivalents, some pyroclastic materials, and some interbedded sediments. Locally (as on Rice Lake) these strata give place, along the strike, to a dominantly sedimentary phase (Wanipigow). The thickness of the volcanic complex is not less than 10,700 feet (Beresford area).

Both sediments and lavas of the Beresford-Rice lakes area have their respective tops toward the north and northeast. The sediments lie, therefore, along the southern margin of the schist belt, and the volcanics and interbedded sediments are along the northern portion. In the Oiseau River belt, such a simple relationship does not exist; in general, the orientation of the strata is believed to be just the reverse. The country between this belt and the Beresford-Rice lakes band, about 20 miles to the north, is largely batholithic granite, and Wright, in 1924, suggested that the granite magma was "intruded along a broad upfolded arch."

Lower English River area.—The Rice Lake sediments and volcanics are traceable eastward into Ontario. Derry described the eastward extension of the Oiseau band in an area between the English River and the Manitoba boundary. The sediments, mainly paragneiss with a little quartzite, graywacke, and granite-pebble-bearing conglomerate, are much metamorphosed and much intruded by granite. Little evidence is presented to establish the age relations of the sediments to associated volcanics. On the Manitoba boundary, at Reyerson Lake, a narrow east-west band of volcanics is flanked by sediments. Because of the lithologic difference of the sediments on the two sides of the volcanics, Derry concluded that the lavas lie between two different sedimentary formations. According to Burwash (1923), the northern sedimentary band carried conglomerates with volcanic rock fragments, so it seemed logical that these were the younger series. In Manitoba, where the same formations were studied by Wright (1924), the age relations were interpreted to be just the reverse.

Dowling, in 1894, and Bruce, in 1924, mapped, in the valley of the English River below Lac Seul, a widespread series of mica schists and paragneisses, which Bruce in 1927 referred to the Coutchiching. Bruce mentions associated iron formation and granite-pebble-bearing conglomerate. Reference to the 1922 report shows that the paragneiss was stated to be intruded by granite, but no other age relations were established, and the correlation with the Coutchiching was not mentioned.

Lac Seul region.—The mica schists and paragneisses of the English River Valley are also found on the northwest arm of Lac Seul, between Shanty Narrows and Gold Pines. In his 1920 report on a geological

reconnaissance into Patricia, Burwash said that they had been studied and had been found to extend up the Wenesaga River to a point just below Slate Lake, though much interleaved granite is included. Burwash examined the rocks microscopically and concluded that they are "soda-rhyolite more or less altered." He accordingly classified them as Keewatin, or what he called the Lac Seul series.[55] Bruce, who has examined similar rocks on Lake St. Joseph, as well as the actual extensions of Lac Seul schists in the English River area, concluded that these schists were sedimentary in origin. The writer, who has seen the Lac Seul exposures, concurs with Bruce.

Lake St. Joseph.—On Lake St. Joseph, Bruce described in 1923, in a series of reports dealing with this area, extensive paragneisses with a well-developed iron formation, associated with quartz porphyry (interpreted as an acid flow), and basic volcanic rocks and their metamorphic equivalents. Granite-pebble-bearing conglomerate is reported in the sedimentary phase in the eastern part of the lake. As a result of a study of drag folds in the iron formation, Bruce concluded that the paragneiss along the southern part of the lake was overlain by the volcanics, which lie, in the main, on the islands and shores of the lake, to the north of the sedimentary schists.

Miniss-Pashkokogan lakes district.—W. S. Dyer remapped part of the Lake St. Joseph area and extended the mapping southward and eastward to the Pashkokogan Lake area. Here, the paragneisses were given the local name Miniss series and were correlated with the Coutchiching, largely on lithologic similarity and on their apparent dip under the volcanics, which were called Keewatin. Much interbedded sedimentary material is reported in the volcanic assemblage. A single outcrop of granite-pebble-bearing conglomerate is reported; it lies within the volcanic complex and is interpreted by Dyer as "infolded Timiskaming."

In summary, the sediments, largely paragneiss, which are found at intervals from the Oiseau River area in Manitoba, through the valley of the English River, on the western end of Lac Seul and north of Lac Seul, and on the south shore of Lake St. Joseph, and eastward, are probably one and the same series. They are along the same general strike line, and some continuity exists between the several known outcrops, which extend for about 300 miles. From all the evidence available, it seems probable that they lie below the associated volcanic rocks and their schist equivalents. They contain some iron formation and a little granite-pebble conglomerate (largely interbedded and lenticular).

[55] E. M. Burwash: *The pre-Cambrian of western Patricia*, Jour. Geol., vol. 30 (1922) p. 394-395.

RED LAKE-SLATE LAKE SEDIMENTS

Red Lake area.—In the region under review and north of the great assemblage of mica schists and associated rocks that extends from the Manigotagan and Oiseau rivers eastward to Lake St. Joseph and beyond, few important sedimentary belts are known.

The most important of these is on the shores of Red Lake, where the relations have been studied by Bruce. In this area, a volcanic assemblage ("Keewatin") with minor interbedded sediments is said to be overlain and infolded with a sedimentary series ("Timiskaming"). The latter consists of slates, graywackes, and conglomerate. The conglomerate bears granite and granite porphyry pebbles. Data relative to the structural relations of these beds to the lavas are meager and inconclusive, though Bruce believes the sediments to be younger.

Quartz porphyry and granite intrude both the sediments and the lavas.

Woman, Slate, Narrow, Shabumeni, and Birch lakes area.—The geology of the schist belt between and surrounding Woman, Slate, Narrow, Shabumeni, and Birch lakes has been studied by Burwash, Grieg, Bruce, and Furse. The bedrock consists of a series of interbedded sediments and lavas and possibly a younger series of sedimentary formations. These have been intruded by granite batholiths and stocks and have locally been much metamorphosed. The structure of the area is as yet incompletely known. Furse, in his description of the Shabumeni-Birch lakes portion of the district, divided the schist complex into three units: (1) lower volcanics, consisting of basic flows, both acid and basic pyroclastics, and iron formation; (2) Shabu series, composed of graywacke, slate, quartzite, and arkose, and conglomerates; and (3) upper volcanics, andesite, basalt, and some rhyolite. This sequence was established by careful study of the position of top and bottom in the near-vertical strata. Furse, however, classed the Shabu series as "Timiskaming type." These strata are "hornblendic," in many places "mixed with lavas," and the conglomerates do not carry granite débris. Bruce interpreted most of the clastic rocks in the adjacent Woman, Narrow, and Confederation lakes area as of volcanic origin, with two possible minor exceptions. Grieg himself noted that only the conglomerates of Slate Lake and Birch Lake River carried granite cobbles and pebbles and might be, as noted earlier by Burwash, correlated with one another. Burwash called these sediments the Birch Lake series.[56] Such structural data as are available indicate that even these granite-pebble-bearing conglomerates may be older than a part of the volcanic complex and younger than other parts.

[56] E. M. Burwash: *The pre-Cambrian of western Patricia*, Jour. Geol., vol. 30 (1922) p. 396.

Cat River-Kawinogans schist area.—Eastward from the territory just discussed, no sediments are known, though in the Cat River-Kawinogans Lake area, a series of volcanics of considerable extent has been recently reported by Harding.

Pickle Lake-Crow River area.—A part of the Pickle Lake-Crow River district is included in the area covered by this paper. This territory was described in 1931 by Hurst. No post-volcanic sedimentary rocks are recognized, though a widespread series of greenstone flows and schists (referred to the Keewatin) is described. These have been intruded by diorite and gabbro and by later series of plutonic acid igneous rocks, as well as by diabase dikes (Keweenawan?).

CORRELATION PROBLEMS

Having summarized and digested all the recent geological literature pertaining to the region, the writer will now summarize the correlational problems and suggest means and places by which, and where, their ultimate solution might be made. Several hypotheses of correlation are presented as an aid and stimulus to further work.

The early pre-Cambrian or "basement complex" and both meta-sedimentary and meta-igneous volcanic rocks have already been described. These are cut by plutonic masses, largely of granitic character. Several possible relations may exist between the rock series mapped and described under various local names.

One hypothesis, the currently popular one, supposes a single period of widespread volcanism—the Keewatin—and all sedimentary rocks believed to be older than the rocks of this period are called Coutchiching, whereas all beds of post-volcanic age are called Knife Lake, Timiskaming, or are given a local series name. Students of the early pre-Cambrian, however, have never reached an agreement as to whether there is, at least in the type area, a significant pre-Keewatin sedimentary series. This is the well-known Coutchiching problem. The later sediments—excepting the Steeprock series, which has an exceedingly limited distribution—have been generally regarded as of about the same age. A very significant break is believed to separate the Keewatin volcanics from the overlying sediments. In fact, this break is regarded by Leith as the most probable line of division between the "Archean" [57] and the "Algonkian."

A second hypothesis, more acceptable than the first, as will be pointed out later, postulates one period of widespread continental sedimentation and two periods of volcanism, one pre-sedimentary ("Keewatin" in

[57] C. K. Leith, R. J. Lund, and Andrew Leith: *Pre-Cambrian rocks of the Lake Superior region*, U. S. Geol. Surv., Prof. Pap. 184 (1935) p. 17-18. Leith, however, defines the Archean, p. 10, as the "basement complex consisting dominantly of igneous rocks (though containing sediments) in which ordinary stratigraphic methods are not applicable."

restricted sense) and one post-sedimentary, to which local names, as Handy Lake volcanics,[58] Neepawa volcanics,[59] have been applied. A significant unconformity separates the sediments from the earlier volcanics, and a second unconformity (disconformity?) separates the upper volcanics from the underlying sediments.

A third hypothesis requires three cycles of sedimentation, followed by volcanism, and separated from one another by significant diastrophism and probably by granitic intrusion. This hypothesis is regarded by the writer, for reasons to be pointed out, as most nearly in accord with the known facts, though demonstration of its correctness must await further field work.

The conclusion that all the volcanics belong to a single period of widespread volcanics—the Keewatin—is not founded on fact but is an assumption. Even though it is now recognized that the Keewatin contains more or less sedimentary material,[60] no good evidence of a major discordance within the complex has been presented.[61] Because satisfactory evidence of two periods of volcanism is generally lacking, and as the "Timiskaming" conglomerates contain greenstone pebbles and were observed in contact with these rocks, an unconformity with the lavas was considered established. Elsewhere, sediments below lavas were noted, and these were referred to the "Coutchiching." In some places, the sediments above the lavas are probably the same as those seen elsewhere below the volcanics, and, instead of one period of volcanism and two of sedimentation, there were two of volcanism and one of sedimentation. Fortunately, some recent work (*e. g.*, Savant Lake and East Bay of Minnitaki Lake) demonstrates the existence of both an earlier and a later period of volcanism. It seems probable, also, that the younger (Kenoran) volcanics are unconformable on the sediments and in places overlap them and rest on the pre-sedimentary volcanics (Keewatin). The term Keewatin will be retained for the older period and the term Kenoran, from the District of Kenora, will be applied to the second or younger period.

Without adequate structural data, most investigators (assuming a single Keewatin period of volcanism and a post-Keewatin or "Timiskaming" period of sedimentation) have interpreted the various "Timiskaming" sedimentary belts as infolded synclines. Where careful structural work, such as graded bedding, shape of pillows, and other features, has been done on the sediments and the associated volcanics, it is found that, with

[58] Gordon Rittenhouse: *Geology of a portion of the Savant Lake area, Ontario*, Jour. Geol., vol. 44 (1936) p. 469.

[59] F. J. Pettijohn: *Geology of East Bay, Minnitaki Lake, district of Kenora, Ontario*, Jour. Geol., vol. 44 (1936) p. 348.

[60] J. F. Wright: *Geology and mineral resources of part of southeastern Manitoba*, Canada Dept. Mines, Geol. Surv. Canada, Mem. 169 (1932) p. 35.

[61] E. L. Bruce: *Coutchiching delta*, Geol. Soc. Am., Bull., vol. 38 (1927) p. 781.

rare exceptions, a synclinal structure does not exist. In many places, where proof is available, the relations found in this subprovince are similar to those found by Collins and Quirke [62] in the Doré area at Michipicoten, where the Doré conglomerate and other sediments overlie the pre-Doré volcanics and are, in turn, overlain by the post-Doré volcanic complex.

This problem—*i. e.*, the question of the dual nature of the Keewatin and the structural relations of the sediments to the volcanics—might be called the "Keewatin problem."

Are the various sedimentary series—*i. e.*, the Seine series, Knife Lake series, Manitou series, Abram series, and others—all of the same age? Such has been the general belief (except, however, for the "Coutchiching" paragneisses). This conclusion is supported by (1) the lithologic similarity of the sediments, all of terrestrial origin and marked by coarse granite-pebble-bearing conglomerates and banded slates; (2) the unconformity at the base of the sedimentary series, with a volcanic basement complex; (3) the structural position of the sediments, as infolded synclinal remnants in the Keewatin volcanic complex; and (4) the recognition of an older granite (not generally observed except as pebbles in the conglomerates) and a widespread younger or post-sedimentary granite, designated Laurentian and Algoman, respectively. In 1916, Lawson, in fact, proposed, as a working hypothesis, to assume that there were two, and only two, periods of granite intrusion, the Laurentian and the Algoman, and that correlation could be accomplished if only the relations of the formations to these two epochs of batholithic intrusion were observed. Such is an admirable basis of correlation, but, in the practical working out, no certain criteria can be drawn for discriminating between the two granites, and it is seldom that any older granite can be found. Moreover, it has been recently established that there are three periods of granitic intrusion in some parts of the shield.[63] This is the "problem of the granites," and its final solution must await more detailed mapping. Most probably, the relative ages of these intrusives will be better determined by study of their relations to the sedimentary belts rather than by their relation to each other and by their petrographic characters.[64]

As pointed out, recent detailed work in the subprovince demonstrates an important later series of volcanics, a different interpretation of the structural relations between the sediments and the lavas, and the recognition of more than two granites in the Lake Superior region. These data

[62] W. H. Collins, T. T. Quirke, and Ellis Thomson: *Michipicoten iron ranges*, Canada Dept. Mines, Geol. Surv. Canada, Mem. 147 (1926) p. 1-141.

[63] *Op. cit.*, p.41-42.

[64] Such has been the case in Finland. *See* E. L. Bruce: *The granites of Finland*, Royal Soc. Canada, Tr., 3d ser., vol. 25, sec. 4 (1931) p. 283.

throw much doubt on the hypothesis of correlation, which postulates only one period of sedimentation in the early pre-Cambrian, most often designated Timiskaming by the Canadian geologists, and Knife Lake by the Minnesota and Wisconsin geologists. The arguments for the third hypothesis of correlation, which assumes a diversity of ages for the different sedimentary belts, is here summarized:

Where it is possible to trace the strata from one district to another without any important gaps, as the Seine series can be traced eastward from Rainy Lake to Block Creek, the correlation between the sediments of one district and those of another can be made fairly well. It is a somewhat less certain matter, however, to correlate between one sedimentary belt and a parallel belt, across a broad area of intervening granite. Moreover, in only a few districts are sedimentary series of two different ages reported. Even in these areas (especially Steeprock Lake area) no unanimity of opinion prevails as to reality of difference in age or of the relative age.

It is now generally believed that the Knife Lake and the Seine series are the same.[65] The term Knife Lake has priority and should, therefore, be applied to these sediments. This usage has recently been followed by C. K. Leith and others.[66] From evidence elsewhere stated, the Manitou series should probably be correlated with the Abram and Savant series and with the Warclub series of Lobstick Bay.[67] As the Savant series has priority, the term should be applied to the rocks formerly given the local names. As already pointed out, the mica schists and paragneisses, which extend from the Rice Lake area in Manitoba to Lake St. Joseph and eastward, are probably all the same, and the name Rice Lake series might be applied to this group of sediments had it not been used to include also the overlying volcanics.[68] Wright has called the lower part, essentially all sedimentary, the Manigotagan phase. This name can, therefore, be used as a series name to replace the local name, Miniss, which Dyer applied to these rocks in the Pashkokagan-Misehkow area.[69] Are the Knife Lake, Savant, and Manigotagan series, as thus defined, all of the same age? At present, some of the sediments included in the definitions given have been

[65] F. F. Grout: *Coutchiching problem*, Geol. Soc. Am., Bull., vol. 36 (1925) p. 354-355.

[66] C. K. Leith, R. J. Lund, and Andrew Leith: *Pre-Cambrian rocks of the Lake Superior region*, U. S. Geol. Surv., Prof. Pap. 184 (1935) p. 16.

[67] F. J. Pettijohn: *Geology of East Bay, Minnitaki Lake, district of Kenora, Ontario*, Jour. Geol., vol. 44 (1936) p. 353.

[68] J. F. Wright: *Geology and mineral deposits of a part of southeastern Manitoba*, Geol. Surv. Canada, Mem. 169 (1932) p. 11. E. S. Moore called the sediments Wanipigow series in 1912 and regarded them all as post-volcanic. Most of the sediments have been shown by Wright to be pre-volcanic (Manigotagan) and the term Wanipigow is retained by him only for the sediments interbedded with the volcanics.

[69] W. S. Dyer: *Geology of the Pashkokagan-Misehkow area*, Ontario Dept. Mines, Ann. Rept., vol. 42, pt. 6 (1934) p. 5-7.

TABLE 1.—*Tentative and hypothetical correlation as postulated by the third hypothesis*

	Period or Cycle	Series*	Synonyms and/or divisions		Principal areas
Late Pre-Cambrian		Major unconformity–gabbro intrusion			
	IV	Keweenawan volcanics and sediments	Sibley volcanics Osler slates		Port Arthur and Thunder Bay areas. Gunflint district, Pigeon River Lake Nipigon basin
		Animikie sediments	Rove slate Gunflint iron formation		
		Major unconformity–granitic intrusion ("Ep-Archean interval")			
Early Pre-Cambrian	III	Knife Lake sediments (with some interbedded volcanics)	Seine Windigokan		Vermilion Range Matawin Range Rainy Lake Seine River Block Creek
		Major unconformity–granite intrusion?			
	II	Kenoran volcanics	Neepawa volcanics Handy Lake volcanics Ely greenstone?		Savant Lake, Sioux Lookout area, Thunder-Eagle lakes area, Manitou Lake, Lake of the Woods, Slate Lake? Sturgeon Lake? Obonga Lake? Steeprock Lake?
		Disconformity			
		Savant sediments	Abram series Warclub series Crowduck conglomerate Manitou series Steeprock series? Birch Lake series?		
		Major unconformity–granitic intrusion			
	I	Keewatin† volcanics	Jutten volcanics Beresford Lake volcanics? Ely greenstone?	Rice Lake series Lac Seul series	Savant Lake Sioux Lookout area Lake of the Woods Rice Lake area
		No unconformity–interbedding			
		Manigotagan sediments	Minisa series Coutchiching‡		English River Rice Lake area Lac Seul Lake St. Joseph Miniss Lake Pashkokogan area
		Unconformity–granitic intrusion			

* Choice of name determined by priority.

† Redefined and restricted.

‡ The Coutchiching of the type locality is much later in age.

called Coutchiching and some Timiskaming. The arguments for, and implications of, a diversity of ages for these sediments are:

(1) The Knife Lake and the Manigotagan sediments have a great areal extent, whereas the Savant sediments are confined to limited narrow bands. This difference is believed to be due to the inclusion of the Savant sediments between two lava series, whereas the Knife Lake and the Manigotagan sediments are not so sandwiched.

(2) Conglomerates are a notable and characteristic feature of the margins of the sedimentary areas of Knife Lake and are, likewise, very extensive and persistent in the Savant series, but notably scarce in the Manigotagan series.

(3) That the present areas of these sediments are not remnants of a once-continuous stratum is attested by the fact that coarse conglomerates are known from nearly all areas, and these conglomerates are apparently wedge-shaped, basin-margin type of deposits and very probably mark, in a rough way, the original margins of the basins of sedimentation in which these various series accumulated.

(4) It has been shown in earlier parts of this paper that the volcanics of the Seine River and the Knife Lake areas are older than the associated sediments; whereas, in the Manitou, the Minnitaki, and the Savant areas, the greenstones are both younger and older than the associated sediments. In the Rice Lake area and the St. Joseph region the volcanics are believed to be dominantly younger than the associated sediments. Moreover, the contact between the Savant sediments in the Savant Lake, the East Bay of Minnitaki Lake, and Mosher Bay of Manitou Lake regions and that of the overlying lavas is distinctly disconformable, whereas the contact between the Manigotagan sediments and the overlying Beresford volcanics of the Rice Lake country is marked by conformity and interbedding. This fact, coupled with difference in lithology, pointed out under item No. 2, suggests a different age for the sedimentary series of the two regions. A lower stratigraphic position or older age for the Manigotagan sediments is implied, for the Beresford Lake volcanics must be the equivalent of the lower volcanic rather than the upper volcanic series of the Savant, Minnitaki, and Mosher Bay areas.

(5) The Steeprock series more nearly resembles the Abram and Manitou rocks than it does those of the Seine River. It lies in such a position and has such a strike that it may well be a continuation of the northwest-trending beds of the Savant (Manitou) series on Stormy Lake. It is overlain by a younger volcanic series, as are the Manitou sediments, and also contains a granite-pebble-bearing conglomerate. On the other hand, limestone is not known in the Manitou sections. Until further work is done in the Steeprock area, many of the problems relating to this series must remain unsolved.

The paragneisses of the English River and St. Joseph areas have been correlated with the Coutchiching on very slender evidence.[70] If the Coutchiching be a metamorphic facies of the Knife Lake beds, as is now generally believed,[71] then the correlation is even more doubtful. The great areal extent, paucity of conglomerate, and apparent pre-lower-volcanic position make doubtful the correlation with either the Knife Lake or the Savant series. It is perhaps, the oldest series of rocks in the subprovince.

(6) The structural relations are suggestive. The strata on Knife Lake have conglomerates mainly along the south margin of the outcrop area (Vermilion Range), whereas the Seine River strata have conglomerates along the northern margins (Seine River to Block Creek). This suggests that these two belts mark the borders of a great geosyncline into which the Vermilion batholith and other plutonics have been intruded. Similarly, the sediments extending from Manitou Lake to Schistose Lake ("Manitou" series) have a prevailing north-facing orientation, and apparently the sediments of Eagle Lake and Thunder Lake have a south-facing orientation. Likewise, the conglomerates of the Manitou area are along the southern margin of the sedimentary belt, and the conglomerates of the Sioux Lookout region are developed almost wholly along the northern edge of the outcrop area. The intervening synclinorium is occupied by the younger volcanic series as well as by the younger granites.

The sixth sedimentary series, the Birch Lake series, known only from fragmentary belts, most nearly resembles the Abram series in lithology, and, as it lies perhaps between two important volcanic series, it may be the correlative of the Savant series. Until a detailed survey of the Slate and Birch Lake regions is made, the relations of these granite-pebble-bearing conglomerates and associated sediments must remain in doubt.

In conclusion, it seems necessary to abandon the terms Coutchiching, Keewatin, and Timiskaming for the strata in this area. Two alternate hypotheses of correlation for the early pre-Cambrian are presented. One supposes two periods of widespread volcanism and an intervening period of continental sedimentation. The other postulates three periods, the lower two composed of two series, one sedimentary and one volcanic, and the upper one largely sedimentary. By this hypothesis, the strata of the six belts are grouped as shown in Table 1. A fourth period is included if the Animikie-Keweenawan of the late pre-Cambrian are added.

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[70] *Op. cit.*, p. 7.
E. L. Bruce: *Coutchiching delta*, Geol. Soc. Am., Bull., vol. 38 (1927) p. 776.
[71] F. F. Grout: *op. cit.*, p. 354-355.

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GLACIATED LOWER SLOPES AND HIGHER SLOPES UNMODIFIED BY ICE

From vertically above Clark Fork of Columbia River near Usk, looking southwest across Pend Oreille Mountains, Colville River valley, and Huckleberry Mountain to Kettle Range on horizon. (Photograph by 116th Photo. Section, Washington National Guard.)

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PLEISTOCENE DRIFT BORDER IN EASTERN WASHINGTON

BY RICHARD FOSTER FLINT

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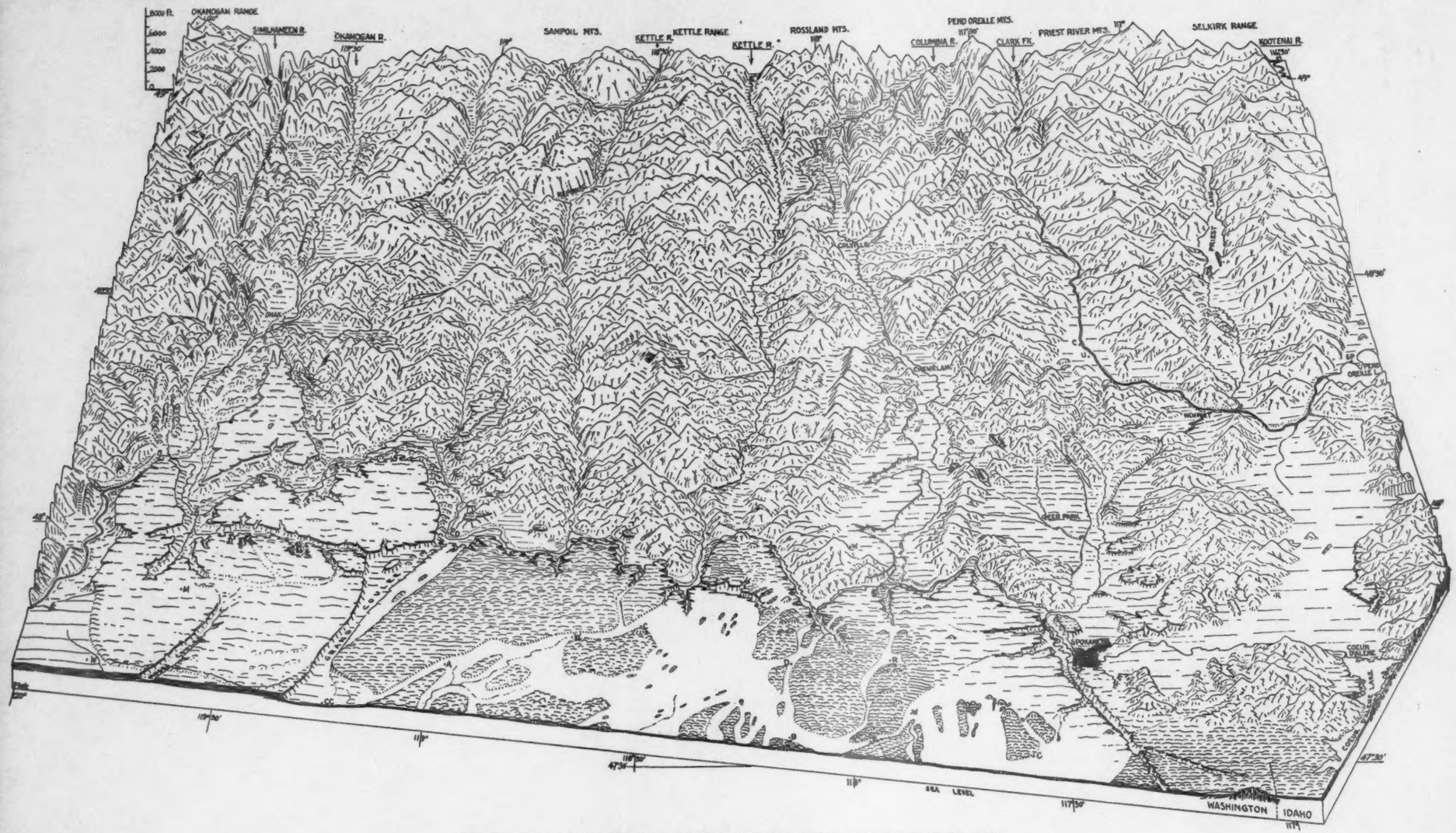
REGIONAL SETTING

In the broad sector included between the continental divide in Montana and the crest of the Cascades in northern Washington, the glacial drift offers a number of important problems, some of which are clearly set forth in the existing literature on this region. The purpose of the present discussion is to review the significant data, to trace the drift border through a part of this sector, and to offer an interpretation of the age of the drift, as a result of three seasons of field study in eastern Washington.

Northeastern Washington (Pls. 2, 5) consists of two very different regions. The more northerly region is a highland marked by northward-trending ranges lying between pronounced parallel valleys, and underlain by rocks predominantly crystalline, among which are abundant granitic and metamorphic rocks, including much argillite. The range crests descend from extreme elevations of more than 7000 feet near the International Boundary, to 3000 feet and less at their southern margins, where they disappear beneath the basalt blanket of the Columbia Plateau. The intervening valley floors range in elevation from about 1800 feet down to about 800 feet. The linear ranges and mountain groups [1] are, from east to west: Priest River Range, Pend Oreille Mountains, Huckleberry Mountain, Kettle Range, Sanpoil Mountains, and the highlands east of the Okanogan River. West of the Okanogan River is the complex Cascade chain, its eastern flank in this latitude represented by the Okanogan Mountains. Between the subparallel ranges are the following valleys, named from east to west: Clark Fork of Columbia River and Little Spokane River; Colville River and Chamokane Creek; Columbia River; Sanpoil River; Okanogan River.

South of the highland is the Columbia Plateau, a thick pile of basalt flows resting against and covering the highland surface, which passes beneath it. The flows dip toward the center of the plateau, and in conse-

[1] The terminology used corresponds, as nearly as is practicable, with current usage by the Washington Division of Geology.



BLOCK DIAGRAM OF NORTHEASTERN WASHINGTON AND PART OF IDAHO

Northern (rear) margin of block is at the International Boundary. Length of front of block—approximately 275 miles.

quence, the plateau surface, which reaches an elevation of 2500 feet or more at its northern rim, slopes southward away from the highland at from 10 to 50 feet per mile. Within a zone extending 50 miles westward from Spokane, the plateau surface is broken by more than twenty prominent hills of crystalline rocks projecting through the basalt and representing the higher summits of the highland surface, which the basalt failed to cover.

The basalt is generally covered by a very tough, compact silt known as the "Palouse soil",[2] locally at least 100 feet thick. This deposit, chiefly or wholly Pleistocene, is of partly eolian and partly lacustrine origin, and has been dissected by local streams into a plexus of mature hills, which in turn have been further modified by eolian deposition and nivation.[3] The dissection and shaping of the hills began long before the glaciation of the region. The present surface is coated with a few feet of superficial loess, younger and less compact than the "Palouse soil," and still in process of deposition.[4] The "Palouse soil" and the superficial loess are discussed more fully in another part of this paper.

The plateau is separated from the highland by the east-west canyons of the Columbia River and its tributary, Spokane River. Both streams assumed their courses along the northern margin of the lava field. Their combined south wall, 800 to 1500 feet high, presented a formidable obstacle to the ice advancing from the highland to the plateau.

Such was the diverse character of the surface invaded by Pleistocene glacier ice. The study of the glaciation falls naturally into two parts: The first concerns the position and general character of the drift border; the second involves the dating of the drift.

CHARACTER AND POSITION OF THE DRIFT BORDER

MEANING OF THE TERM

As used in this discussion, the term *drift border* refers to a line tangent to the outermost or uppermost till and erratic stones deposited directly by the ice. It does not refer to outwash, which is known to extend down the Columbia to the Pacific Ocean. In spite of this restriction of its

[2] Kirk Bryan: *The "Palouse soil" problem*, U. S. Geol. Surv., Bull. 790 (1927) p. 21-45.

[3] I. C. Russell: *A reconnaissance in southeastern Washington*, U. S. Geol. Surv., Water Supply Paper 4 (1897) p. 67.

V. R. D. Kirkham, *et al.: Origin of Palouse hills topography*, Science, n. s., vol. 73 (1931) p. 207-209.

W. A. Rockie: *Snowdrifts and the Palouse topography*, Geogr. Rev., vol. 24 (1934) p. 380-385.

See also Plate 4, figure 1 in the present paper.

[4] This is the deposit referred to by Waters and Flagler [A. C. Waters and C. W. Flagler: *Origin of the small mounds on the Columbia River plateau*, Am. Jour. Sci., 5th ser., vol. 18 (1929) p. 212] as volcanic ash. Petrographic examination of this material from the exposure at Cheney, described later in the present paper, shows that, although the heavy minerals consist almost entirely of volcanic ash, the bulk composition includes only a relatively small proportion of such material [P. D. Krynine: *Age of till on "Palouse soil" from Washington*, Am. Jour. Sci., 5th ser., vol. 33 (1937) in press].

meaning, the term *drift border* is more appropriate than *ice margin*, because it refers to a feature actually present, whereas the former ice margin in many places extended beyond and above the related drift border.

GRAND COULEE—CHELAN DISTRICT

As the drift border varies in its expression from place to place, it will be convenient to divide it into regional segments, and to discuss each as a unit. Probably the most conspicuous unit is the segment that crosses the Columbia Plateau between Chelan and the Grand Coulee. The drift border on the plateau is marked by a massive end moraine, locally 200 feet high, which was described by Russell [5] and traced in detail by Garrey.[6] The first map of its course was published by Bretz,[7] and later discussions have been given by Waters [8] and by Flint.[9] At its western end, the moraine disappears along the east wall of the Columbia canyon, into which it descends. It is well developed eastward to the west brink of the Grand Coulee, where it ends abruptly. It is neither present on the west wall, nor visible on the floor of the coulee, although it might be present here, buried beneath a fill of Nespelem silt.[10]

Along the full length of the west rim, north of the end moraine, the record of glaciation is clear. Further, the coulee floor carries gravel knolls that apparently were built close to the ice. But if the ice reached east of the coulee, its record is lost in the scabland [11] that forms a shelf east of the east rim. In any case, the ice here could not have extended far, for the "Palouse soil" surface east of the shelf bears no marks of glaciation. With due allowance for this margin of error, the parallelism of the drift border with the great trench formed by the upper Grand Coulee is striking. It is probable, indeed, that the farthest advance of the latest glacier in this sector was determined by this trench, although the trench itself may have been localized, in part, along the margin of an earlier glacier.

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[5] I. C. Russell: *A geological reconnaissance in central Washington*, U. S. Geol. Surv., Bull. 108 (1893) p. 86-87.

[6] G. H. Garrey: *Glaciation between the Rockies and the Cascades . . .*, dissertation submitted to Ogden Graduate School of Science, University of Chicago, for degree of M.A. (1902). Typescript, 93 pages. Results summarized in R. D. Salisbury: *Glacial work in the western mountains in 1901*, Jour. Geol., vol. 9 (1901) p. 721.

[7] J Harlen Bretz: *The channeled scablands of the Columbia Plateau*, Jour. Geol., vol. 34 (1923) p. 574, fig. 1; *The channeled scabland of eastern Washington*, Geogr. Rev., vol. 18 (1928) pl. 5, facing p. 476.

[8] A. C. Waters: *Terraces and coulees along the Columbia River near Lake Chelan, Washington*, Geol. Soc. Am., Bull., vol. 44 (1933) p. 785-787.

[9] R. F. Flint: *Glacial features of the southern Okanogan region*, Geol. Soc. Am., Bull., vol. 46 (1935) p. 177-180.

[10] J Harlen Bretz: *The Grand Coulee*, Am. Geog. Soc., Spec. Pub. 15 (1932) p. 37-38.

[11] Scabland is the name given locally to tracts of basalt denuded of their cover of "Palouse soil." *See* J H. Bretz: *The channeled scablands of the Columbia Plateau*, Geol. Soc. Am., Bull., vol. 31 (1923) p. 617.

HIGHLAND NORTH OF THE PLATEAU

General description.—In the rugged highland north of the plateau, the drift border is much less distinct. In 1901, Garrey [12] indicated its probable course, locating accurately its position on the west flank of the Sanpoil Mountains, at the point where it crosses the north end of Huckleberry Mountain, and its approximate crossing of the Pend Oreille Mountains. He placed the positions of the valley ice-tongue margins considerably too far north. In 1913, Stewart [13] stated that the ice in the Clark Fork Valley was continuous eastward across the Priest River Mountains into northern Idaho. According to the writer's observations, this is true of the northern part of the range, but not of the southern. In 1918, Pardee [14] gave some data on the drift border within the Colville Indian Reservation.

In this region, end moraine has been found at the drift border in few places. The border has been determined as a line tangent to the uppermost ice-carried stones on the flanks of the prominent mountain ranges. Other evidence of glaciation is abundant in the major valleys and on the lower slopes: till, ice-abraded and striated rock surfaces, and notched spurs are present, but such features rarely are found at elevations as high as the scattered foreign stones on the mountain sides (Pl. 1). The record of the higher levels of the glacier ice is depositional rather than erosional. Although till is not found at elevations as high as the highest stones, not uncommonly the stones disappear upward rather abruptly, giving fairly satisfactory control for the drift border. As thus determined, the elevation of the drift border at any point is a minimum figure. Neither the thickness of a possible upper zone of ice from which there was no deposition, nor the amount of postglacial movement of the stones downslope, can be determined. Probably, however, the discrepancy between the drift border and the actual upper surface of the former ice is not great, as measurements at several points along one range, as well as measurements on successive ranges in the same latitude, give fairly consistent results.

Traced on this basis, the drift border trends northward from the Columbia Canyon at a point about 6 miles east of the Grand Coulee, along the west flank of the Sanpoil Mountains. In some places, local fills of stratified drift are banked in small tributary valleys at elevations higher than the highest glacial stones. The border rises northward and crosses the mountains at an elevation of more than 3000 feet, 20 miles north of the Columbia. Through a mile-long sector, at and west of the crossing,

[12] G. H. Garrey: *op. cit.;* summarized in R. D. Salisbury: *op. cit.*, p. 721-723.
[13] C. A. Stewart: *The extent of the Cordilleran ice sheet*, Jour. Geol., vol. 21 (1913) p. 427-430.
[14] J. T. Pardee: *Geology and mineral deposits of the Colville Indian Reservation, Wash.*, U. S. Geol. Surv., Bull. 677 (1918) p. 50-53.

the drift border is marked by a well-defined end moraine consisting of rubbly till. From a maximum height of 50 feet and a maximum breadth of less than 200 feet at the range crest, it disappears a short distance down the east flank of the range but continues obliquely down the west side for nearly a mile, becoming gradually less distinct, until it merges into the scattered stones that typically mark the drift border in this region.

No other well-defined morainal ridge has been observed at the drift-border position, but at a few points back within the glaciated area there are short end moraines marking recessional positions of the margins of ice lobes. One of the most accessible is a ridge of coarse rubble with maximum dimensions of 75 feet in height, 200 feet in width, and about 2500 feet in length, in the NE ¼ sec. 8 and the NW ¼ sec. 9, T.30N., R.41E., at the east base of Jumpoff Joe Mountain.

The drift border lies along the west flank of the Kettle Range, forming, with the border on the east flank of the Sanpoil Mountains, a long narrow lobe in the Sanpoil Valley, which will be described separately. Crossing the crest of the Kettle Range at about 5500 feet, 40 miles north of the Columbia, the border trends southward, gradually descending the east flank of the range, to the Columbia River and the plateau.

Nunatak areas.—Except for the Sanpoil Mountains and the Kettle Range, all the ice-free high points in the highland were surrounded by ice during the glacial maximum, and so formed nunataks. The highest parts of the Okanogan Mountains rose above the drift border, at elevations of from less than 6000 feet at the south, to considerably more than 7000 feet near the International Boundary. Three peaks of the Moses Mountain group were ice-free above elevations of from 4200 feet (south) to 4800 feet (north). Several peaks of the Kettle Range were nunataks above elevations from 5500 feet (south) to 6700 feet (north). Huckleberry Mountain, the Pend Oreille and Priest River mountains, and the Mt. Spokane mass (part of the Selkirk Range) formed extensive ice-free areas with disconnected nunataks like satellites near their margins. On each of the larger nunataks the drift border is lower at the south end than at the north.

In general, evidence of ice abrasion is stronger, and the drift border is more clearly marked, on the western flanks of the linear ranges and nunatak areas, than on their eastern flanks. This may mean that the feeding valley glaciers coming from the northwest were more effective than those from the northeast.

Sanpoil lobe.—In the southern part of the Sanpoil Valley, the drift border is peculiar in that the ice margin ended in a lake. A partly dis-

sected fill (the Nespelem silt terrace [15]) of laminated silt and clay, 700 feet or more in thickness, occupies the valley. Interbedded with these deposits are zones of till and deformed strata recording the presence of an active ice lobe during the accumulation of the lacustrine sediments. The drift border here, as in the highland, fails to record the maximum extent of ice. Exposures of till intercalated in the lake sediments are found down the valley to within 6 miles of the mouth of the Sanpoil. Coarse sand interbedded with the silt and clay along the south wall of the Columbia canyon opposite the mouth of the Sanpoil suggests that the Sanpoil lobe may have approached this place.[16] The ice did not, at any rate, encroach on the plateau, whose "Palouse soil" surface here is free of any indication of glaciation.

CRESTON-SPOKANE DISTRICT

General description.—In the vicinity of Creston, near the mouth of the Spokane River, the drift border again encroaches upon the plateau. Three versions of a map showing the drift border in this district have been published by Bretz.[17] The earliest shows the drift border farthest south, and comes nearer than the others to the writer's determination. The criteria used, although not stated in detail, appear to be faceted and striated boulders on the nearly bare basalt surface of the plateau in the vicinity of Spokane and among the hills dissected from the "Palouse soil" at Spangle, and a deposit of kame or outwash gravel at Pantops near Spokane. The second and the latest versions place the drift border successively farther north, although the accompanying text does not explain the basis for the change. The writer agrees that the boulders record the presence of ice, but because their southward extent is considerably greater than is shown on even the earliest version of Bretz' map, and because till and ice-modified topography likewise are found farther south, as will be later indicated, it seems necessary to place the drift border well beyond the line determined by Bretz.

Throughout this district, the drift is patchy, and its entire course eastward upon the plateau is unmarked by end moraine. Yet, on the "Palouse soil" surface, its position is determinable with fair accuracy by

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[15] R. F. Flint: *Stratified drift and deglaciation of eastern Washington*, Geol. Soc. Am., Bull., vol. 47 (1936) p. 1849-1884; *Glacial features of the southern Okanogan region*, Geol. Soc. Am., Bull., vol. 46 (1935) p. 186, and earlier references there given.

[16] R. F. Flint: *Stratified drift and deglaciation of eastern Washington*, Geol. Soc. Am., Bull., vol. 47 (1936) p. 1871, 1873.

[17] J Harlen Bretz: *Glacial drainage on the Columbia plateau*, Geol. Soc. Am., Bull., vol. 34 (1923) p. 574, fig. 1; *The channeled scablands of the Columbia plateau*, Jour. Geol., vol. 31 (1923) pl. 3, facing p. 618; *The channeled scabland of eastern Washington*, Geogr. Rev., vol. 18 (1928) pl. 5, facing p. 476.

the use of two criteria, till and erratic stones, and ice-modified topography.

Till and erratic stones.—Numerous sections exposed throughout the Creston-Spokane district show a layer of till (Pl. 3, fig. 1) between the "Palouse soil" surface and the overlying loess mentioned earlier in the present discussion. The till layer ranges from a few inches up to 10 feet in thickness, and consists of grit, stones, and boulders in an abundant matrix of silt similar to the underlying "Palouse soil" except that it is locally gritty. The till is found throughout a considerable vertical range, and was clearly plastered upon the surface of the "Palouse soil" after the latter had been dissected to very nearly its present expression. It is not, however, a continuous sheet, but is very patchy. In some places the till is absent; in others it is represented only by scattered stones having glaciated shapes and derived from outcrops in the highland north of the plateau. Within the region underlain by the till, similar stones and even large boulders at the surface rest upon the loess, throughout a vertical range of 300 feet. Bretz [18] mentions them as "floated granite erratics" but does not further indicate their mode of deposition. They appear to have reached these positions in part through having been washed out from beneath the superficial loess, and in part through having been frost-heaved up through the loess where it is thin. These processes are not difficult to visualize in view of the fact that throughout the district, great numbers of small knobs of the "Palouse soil" reach up through the loess to the present surface. Fragments of the underlying basalt, some of them rounded, are known in the "Palouse soil" far south of the glaciated region, but the non-basaltic rocks from the highland have thus far been found only in the general district in which till appears in the sections. Hence, the stones may be used in mapping the drift border in places where till has not been found. The stones decrease in size and number toward the south, and in the drift-border zone they are commonly a mixture of local rock types and very resistant types such as quartzites and tough argillites, which can withstand long-distance glacial transportation.

Similar boulders are found in and adjacent to the scabland tracts, but as boulders in such positions may well have been water-borne beyond the glacier, they have not been used in determining the drift border.

Pebbly silt has been described by Bretz [19] as having been built in backwaters, ponded by great proglacial streams, in the Walla Walla and

[18] J Harlen Bretz: *The channeled scablands of the Columbia plateau*, Jour. Geol., vol. 31 (1923) p. 647.

[19] J Harlen Bretz: *Alternative hypotheses for channeled scabland*, Jour. Geol., vol. 26 (1928) p. 325-328; *Valley deposits immediately east of the channeled scabland of Washington*, Jour. Geol., vol. 27 (1929) p. 393-427, 505-541.

FIGURE 1. TILL (STONY) OVERLYING RESIDUAL CLAY (LIGHT-COLORED) AND OVERLAIN BY LOESS
South face of clay pit at Freeman. Till layer is 3 feet thick.

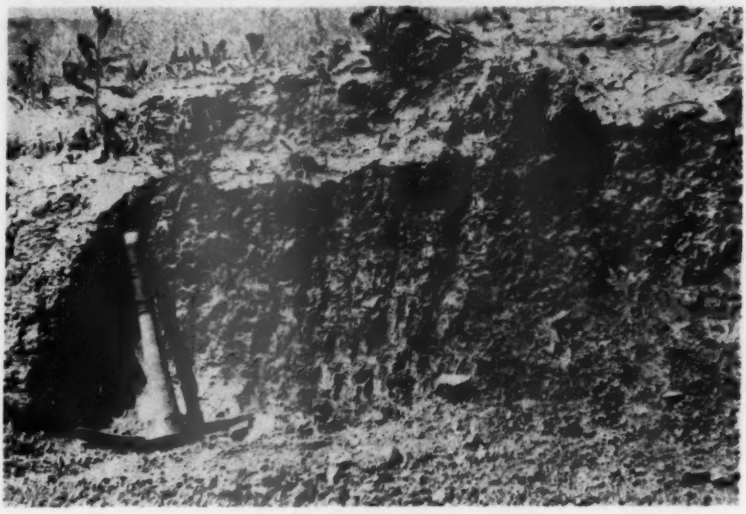


FIGURE 2. DETAIL OF TILL EXPOSURE
At a point, 0.1 mile north of Waukon Grange, southeast corner sec. 14, T. 24 N., R. 39 E. Note angular stones.

TILL

FIGURE 1. UNMODIFIED BY GLACIATION
Looking southeast, from north ½ sec. 23, T. 23 N., R. 39 E., north of Fishtrap.

FIGURE 2. MODIFIED BY GLACIATION
Looking south from north line, sec. 3, T. 25 N., R. 40 E., northeast of Reardan. Hills of crystalline rock projecting through the basalt near Medical Lake are visible on the horizon.

"PALOUSE-SOIL" TOPOGRAPHY

Snake valleys, and in smaller valleys, 20 to 100 miles beyond the drift border. This silt is unlike the material already described, in that it is commonly stratified, and forms terrace-like bodies with nearly flat upper surfaces more or less accordant with the outwash surfaces in adjacent main valleys. The material in question is not stratified, and has no topographic expression of its own; it is a patchy veneer on the dissected surface of the "Palouse soil" at various elevations.

Ice-modified topography.—South of the glaciated region, the topography of the "Palouse soil" is very regular, with a systematic drainage pattern. Individual hills have steep slopes, ranging up to 20 degrees (Pl. 4, fig. 1). But in the Creston-Spokane district, the regularity and system are modified (Pl. 4, fig. 2). Slopes are reduced so that few are as steep as 10 degrees, relief is reduced, minor interfluves become irregular, and divides between two opposing stream heads are locally cut through. The topography is not quite the swell-and-swale of typical ground moraine, but it is clearly abnormal. It lacks the lateral scarps and the continuity of slope that characterize stream-erosional topography in the "Palouse soil" beyond the glaciated region, and cannot, therefore. be a product of stream erosion.

These modifications become more apparent northward, vertically downward, and immediately adjacent to the larger north-south streamways on the plateau. Most important of all is that the region in which the surface is thus modified corresponds closely with the region in which till and erratic stones are present. The facts already cited point to the conclusion that the topographic modification is the result of direct glacial erosion of the preglacially dissected "Palouse soil."

Traced as a line tangent to the outermost foreign stones and modified topography, the drift border is distinctly lobate in detail, the minor projections corresponding with the larger valleys. In those valleys that are cut entirely in the "Palouse soil", the entire lobe can be traced; in those in which the "Palouse soil" has been broadly breached by proglacial meltwater to expose the underlying basalt as scabland, only the lateral margins of the lobe can be traced, because of thorough erosion by the meltwater streams. In such places, the margin of the lobe is restored on the map with an appropriate convention. Many of the reentrants between the lobes were determined by hills of crystalline rock projecting above the basalt. These forced the advancing ice to flow around them. In addition, at least six such hills formed isolated nunataks (Pl. 4, fig. 2). These supply data from which the thickness of the ice on the plateau can be inferred.

In spite of local uncertainties, the outer and upper limits of glaciation are in most places well marked. This limit is recognizable, independent

of age correlation and of the question of whether more than one glaciation is represented; it is shown on Plate 5.

The foregoing discussion involves the tracing of the drift border and the criteria upon which the tracing is based. In the next section the dating of the drift is considered.

AGE AND CORRELATION OF THE DRIFT

FEATURES INDICATIVE OF RELATIVE AGE

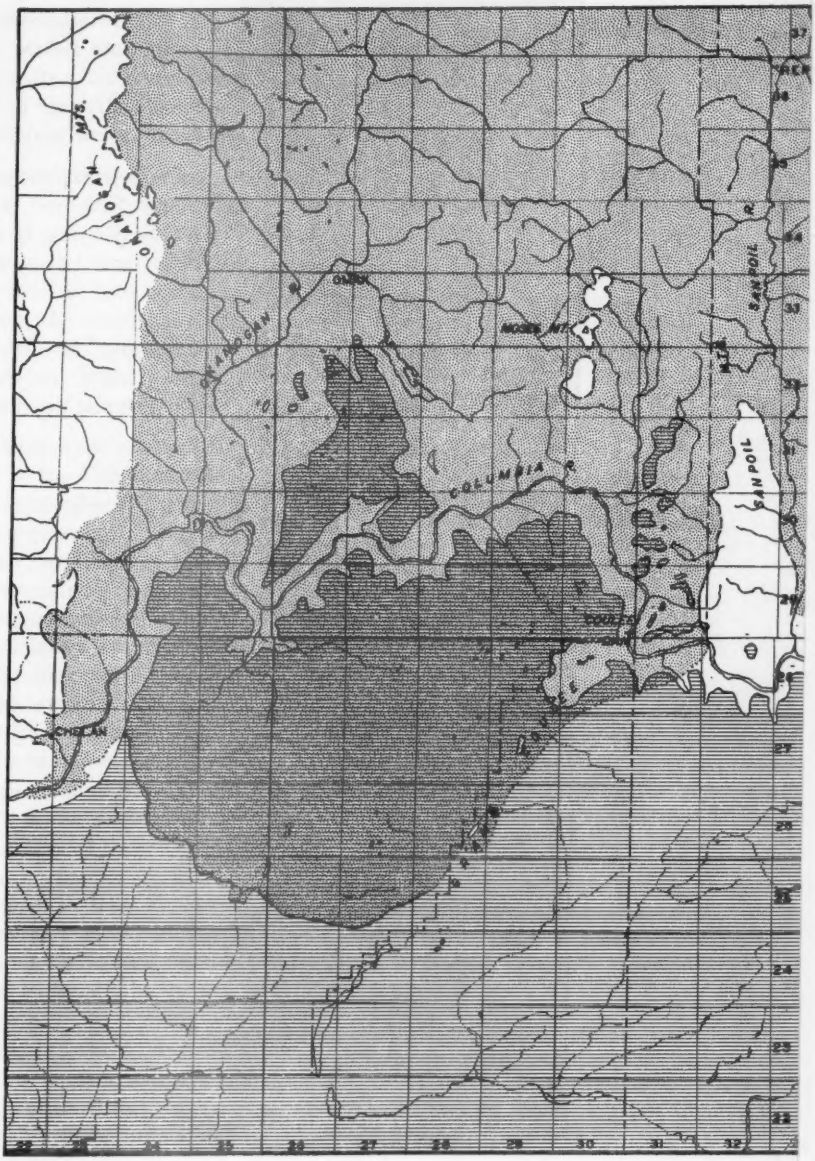
Interglacial features.—Ideal evidence of multiple glaciation consists of exposures showing two or more drift sheets separated by zones of interglacial weathering and interglacial deposits carrying distinctive fossils. Such exposures have not yet been found in eastern Washington. Sections showing two zones of till are exposed, but as they are intercalated in an otherwise continuous succession of laminated silt and clay, they clearly record very minor readvances of a single ice sheet.

Degree of weathering.—Weathering is another feature commonly relied on as a relative measure of time. However, no marked differences in degree of weathering *in situ* among various exposures in eastern Washington have been observed. The soil profiles are of the skeleton type, and the drift, in general, is very fresh. This indicates a late-Pleistocene date for the drift, and is in part a result of the semi-arid climate of the region, in which rock decay takes place slowly. Degree of weathering, therefore, appears to afford no reliable evidence of multiple glaciation in eastern Washington.

Exposures within the drift-border zone in the Creston-Spokane district show till containing large proportions of decayed material. These are no exceptions to the foregoing statement, as all include varying proportions of entirely fresh material of the same lithologic types, the degree of decay bearing no relation to position in the till. It is evident that the decay antedated the glaciation during which the till was formed. This matter is discussed more fully in a later section.

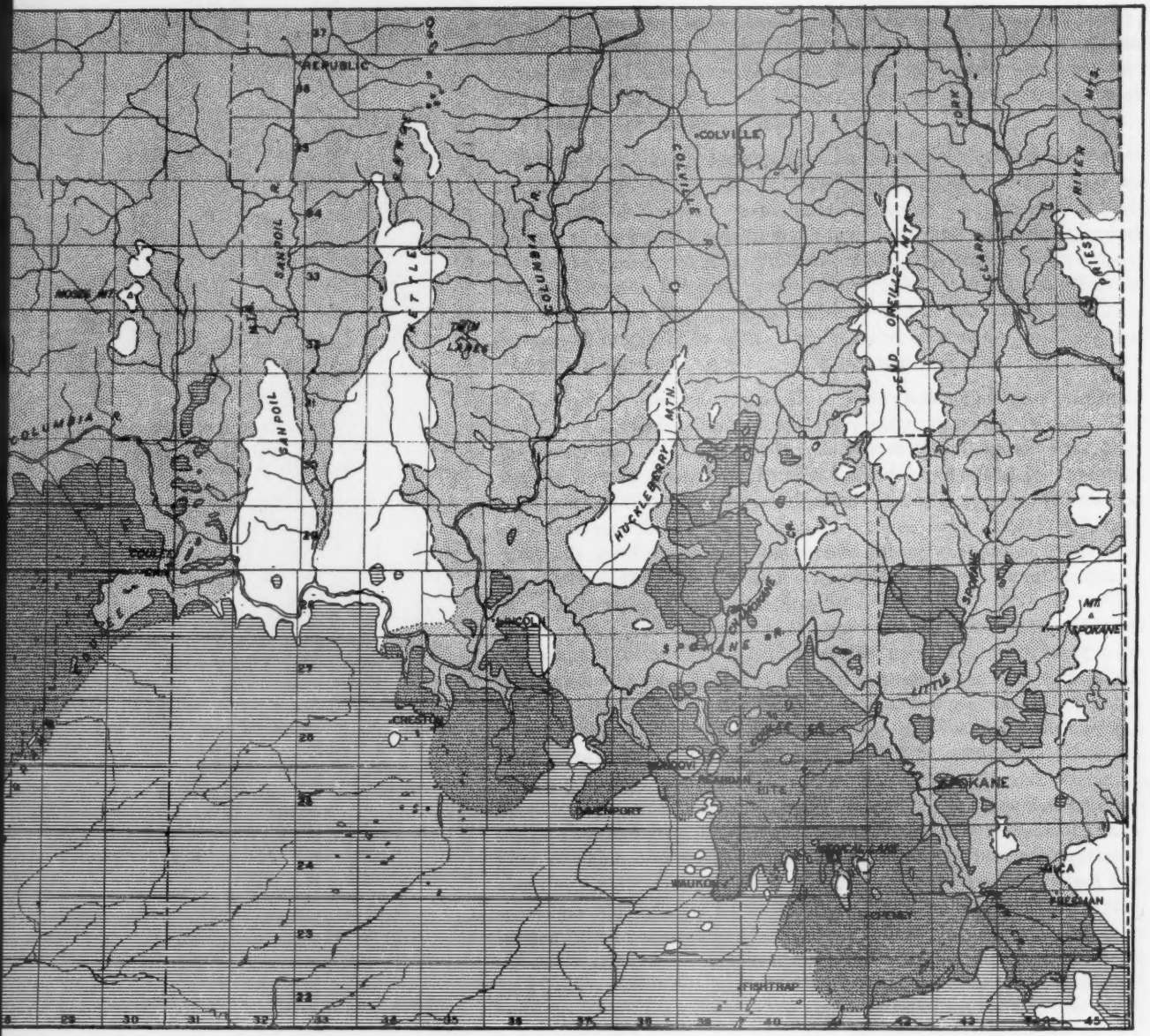
Although not involving deposits, the degree of weathering of striated and otherwise ice-abraded bedrock surfaces has been used in other regions as an indicator of time. This criterion fails in eastern Washington in that the development of ice-abraded rock surfaces decreases progressively (1) toward the south, (2) vertically upward, and (3) from stoss to lee slopes. The variation appears to be a measure of the relative effectiveness of ice work rather than of time.

Degree of cementation.—The thoroughness with which the drift is lithified by cementation is no criterion of age in eastern Washington, where



DRIFT BORDER IN

Horizontal ruling = basalt, somewhat generalized (in part after Pardee, Un
Bulletin 20 (1920) plate 1; Pardee and Bryan, United States Geological Survey Prof
Broken line = outer or upper limit of till and erratics. Dotted line = drift border
1 square = 6 miles on a side. Although this map shows a large area north of the drif
the drift border itself.



DRIFT BORDER IN NORTHEASTERN WASHINGTON

generalized (in part after Pardee, United States Geological Survey, Bulletin 677 (1918) plate 1; Weaver, Washington Geological Survey, United States Geological Survey Professional Paper 140A (1926) plate 1). Stippling = glaciated region. Hatched line = end moraine. d erratics. Dotted line = drift border interpolated across scablands and deep canyons. Base from United States Geological Survey. Scale: ap shows a large area north of the drift border for purposes of reference, the field study that forms the basis of this paper was confined to

single exposures show loose non-cemented stratified drift grading laterally, with perfect continuity of beds, into material well cemented with calcium carbonate. No correlation of degree of cementation with any other feature of the drift, other than its location with respect to the circulation of subsurface water, has been found.

Surface form.—Degree of dissection has been used elsewhere as a measure of post-drift time. This criterion must be applied over as large an area as possible, in order to minimize the strong local influence of such features as texture of the drift, depth to bedrock, and initial slope, and at best must be used with great caution. Having due regard for these local factors, the writer has been unable to recognize any significant difference in degree of dissection among the bodies of drift in this region. The constructional form of the drift (end moraine, ice-contact features, and others) is discussed in another part of this paper.

Thickness of overlying loess.—Dust is now accumulating on and adjacent to the Columbia Plateau, and the plateau loess records that which has accumulated in the past. It follows that the thickness of the loess capping various glacial deposits might afford a measure of the time that has elapsed since the deposits were formed. An attempt to use this method has been made,[20] but it was based on the premise that drift of three distinct dates (discussed elsewhere in the present paper) was present in the Spokane district, and it did not take account of the effect of local conditions on the thickness of the loess capping.

The arbitrary measurement of the loess capping at any one point is not significant of the relative date of the surface on which it rests, because the thickness varies considerably from point to point on the same surface and within the same small area. The areal and vertical position of the point in question, the angle of slope and orientation of the subloess surface, and the texture of the underlying material must all be considered. Thus, the loess is generally thicker on the plateau than on the highland, thicker on lee slopes than on windward slopes, thicker on flat surfaces than on steep scarps, and thicker on fine-textured deposits than on very coarse deposits. Dust may have been washed off steep slopes of slightly permeable material about as rapidly as it lodged on them, and it may have been sifted into coarse gravelly deposits, or washed down into them by percolating water, leaving little or no accumulation at the surface. In shallow exposures in eastern Washington, every gradation from distinct cappings of nearly pure loess is visible resting distinctly on unlike material below, to slightly "dirty" surface zones showing admixture of small amounts of fine silt in

[20] Kirk Bryan: *The "Palouse soil" problem*, U. S. Geol. Surv., Bull. 790 (1927) p. 25-26, 41-44.

gravel which becomes "clean" downward. The thickest capping of loess on glacial deposits seen by the writer amounts to 9 feet (NW corner sec. 1, T.23N., R.44E.), although it rarely exceeds 3 feet. No exposure has been seen in which there is not at least some admixture of silt in the surface zone.

Relation to underlying surface.—In certain parts of the region, drift rests directly upon surfaces believed to have been cut by meltwater before the deposition of the drift. This evidence is discussed later in the present paper.

CRESTON-SPOKANE DISTRICT

"Palouse soil."—The age determination of the drift in the Creston-Spokane district depends in part upon an understanding of the underlying "Palouse soil," mentioned in the introduction to this paper. Bryan [21] gives a historical summary of earlier work on the "Palouse soil" and describes it as including an "upper skin or veneer" of loessial soil over a more compact substratum, reddish, and generally without stratification, which he believes may be "an old loess once similar to the overlying soil but more compacted and oxidized." Judging from the heights of hills, he estimates the thickness of the whole mass at from 100 to 150 feet.

Cuts along new state and county highways in the Spokane district afford more and better exposures than were formerly present; two of the deepest are at Hite station and in the center of sec. 1, T.23N., R.44E. In these exposures, the contact between the "upper skin" and the compact substratum is very distinct, and, as will be indicated, is marked at a number of localities by a layer of till. The "upper skin" is a deep-buff to dark-brown silt ranging in thickness from 1 or 2 to 9 feet. It lacks stratification, but locally shows faint vertical jointing. A skeletal soil profile is developed in it. This layer conforms fairly well with the present hillslopes, and evidently was deposited after the compact substratum had been sculptured to approximately its present mature topographic expression—the "Palouse topography" of local geologists. These facts confirm the opinion expressed by Byran that the "upper skin" is a loess.

In the Spokane district, the substratum is a very tough, compact, fine silt to clayey silt, ordinarily without any stratification. Near its upper surface it is colored pale chocolate when wet, and deep buff to reddish brown when dry; small black mottlings are common in it. It is seamed with irregular fractures along which the silt slacks and checks when dry. Many of the fracture surfaces are shiny, possibly as a result of slippage, or

[21] *Op. cit.*, p. 22.

colloid deposits in the fractures, or both. At greater depths the color pales to a buff or brown, and the mottlings and fractures become less numerous. Although no more than 30 feet of this substratum has been observed in any single exposure, it is probable that it is considerably thicker.

The writer agrees with Bryan [22] that the common age and origin of all parts of the "Palouse soil" are doubtful, and that definite proposals regarding terminology must await the results of detailed study of this body of sediment throughout its extent. In the Spokane district, however, the "upper skin" is so clearly distinct in character and date from the substratum, that for the purpose of the present discussion, the writer prefers not to treat it as a part of the "Palouse soil." Accordingly, it will be referred to here as the superficial loess, which rests upon the compact "Palouse soil."

"Old drift."—The glacial features of the Creston-Spokane district have thus far received very brief discussion,[23] in which, however, the presence of three separate bodies of drift have been suggested: an "old drift," a "Spokane" (or "intermediate") drift, and Wisconsin valley-train outwash. Each of these bodies will be considered.

In 1917, Leverett reported [24] the occurrence near Cheney of "a very old drift, probably Kansan." This drift has been referred to also by Large,[25] Bretz,[26] Freeman,[27] and Bryan.[28] Bretz reported it from one other locality (Medical Lake) in the vicinity of Spokane, and Bryan from two (Pleasant Prairie and Fivemile Prairie). Although Leverett gave no description of this drift, it is clear from the later references cited, that it is a till, regarded as old because (1) it includes weathered stones, (2) its matrix is weathered, and (3) it is overlain by loess.

The Cheney exposure is in an abandoned pit at the west edge of the State Normal School grounds. The cut is about 150 feet long, but the

[22] *Ibid.*

[23] T. W. Symons: *Report of an examination of the upper Columbia River . . .*, Senate Ex. Doc. 186, 47th Congr., 1st Sess., Washington (1882) p. 107.

M. R. Campbell: *Guidebook of the western United States*, U. S. Geol. Surv., Bull. 611 (1915) p. 162, 163.

M. M. Leighton: *The road-building sands and gravels of Washington*, Wash. Geol. Surv., Bull. 22 (1919) p. 246.

Cornelius Van Duyne, *et al.*: *Soil survey of Spokane County, Washington*, U. S. Bur. Soils, Field Operations 1917 (1921) p. 29.

Thomas Large: *Glacial border of Spokane*, Pan-Am. Geol., vol. 38 (1922) p. 359-366.

J Harlen Bretz: *Glacial drainage on the Columbia Plateau*, Geol. Soc. Am., Bull., vol. 34 (1923) p. 580-583, 586; *The channeled scablands of the Columbia Plateau*, Jour. Geol., vol. 31 (1923) p. 622-623, 646-648.

[24] Frank Leverett: *Glacial formations in the western United States* [abstract], Geol. Soc. Am., Bull., vol. 28 (1917) p. 143.

[25] Thomas Large: *op. cit.*, p. 362.

[26] J Harlen Bretz: *Glacial drainage on the Columbia Plateau*, Geol. Soc. Am., Bull., vol. 34 (1923) footnote, p. 588-589.

[27] O. W. Freeman: *Mammoth found in loess in Washington*, Science, n. s., vol. 64 (1926) p. 477.

[28] Kirk Bryan: *op. cit.*, p. 25-26, 33, 42-43.

face now requires digging for clean exposures. The section exposed in 1935 is as follows:

Surface (Mature hillslope in "Palouse topography")

	Feet
Loess, deep buff to dirty brown	2.0 to 4.0
Till, consisting of grit and stones[29] including argillite, quartzite, granite, and basalt, both faceted and rounded, thoroughly mixed in a matrix of tough clayey silt, megascopically similar to the underlying material, though slightly paler in color	5.0 maximum
Silt, deep buff, very compact, non-stratified, with black mottlings and shiny fracture surfaces	8.0 exposed

—Base concealed—

Bretz [30] did not find this till on the scabland nor on the glaciated surface to the north; he concluded that it antedated the glaciation responsible for the scabland. Examination of recently made cuts, however, has shown till on two scabland intakes and in the glaciated area northeast of Reardan. The localities, together with others in which similar till is found, are given herewith:

1. W ½ sec. 33, T.29N., R.36E., about 5 miles N of Lincoln. Several road cuts showing 4-ft. layer of foreign stones in "Palouse-soil"-like matrix.
2. NE ¼ sec. 13, T.25N., R.37E. Cut on highway US-10, about 3 miles NE of Davenport. 18-in. layer of till consisting of foreign stones in abundant matrix like "Palouse soil." Rests on clean surface of fresh basalt, and overlain by 18 in. of superficial loess.
3. NW cor. sec. 35, T.26N., R.38E., about 3 miles NE of Mondovi. In road cut: 2 ft. of stony grit in "Palouse-soil"-like matrix. Rests on "Palouse soil" and overlain by 3-4 ft. of superficial loess.
4. W line sec. 1, T.25N., R.39E., about 3 miles NE of Reardan. In road cut: Lens 25 ft. long, max. 18 in. thick, of stony grit with till balls and balls of "Palouse soil," resting on "Palouse soil" and overlain by max. 8 in. of superficial loess.
5. Center E line sec. 14, and SE cor. sec. 14, T.24N., R.39E., about 2 miles N of Waukon. 2-4 ft. of till, consisting of stones in "Palouse-soil"-like matrix, and resting on "Palouse-soil." Both overlain by max. 2.5 ft. superficial loess.
6. Center W line sec. 31, T.26N., R.40E. Cut on Spokane-Lincoln county-line road: 4-in. zone of stony grit in "Palouse-soil"-like matrix, grading down into "Palouse soil" and overlain by max. 3 ft. superficial loess.
7. W line sec. 28, T.26N., R.40E. Cuts along N-S county road between Hite station and Coulee Creek. Show numerous exposures of till and stony zones, overlain by 2-3 ft. of superficial loess, and resting on "Palouse soil." Till and stones discontinuous; better developed on N-facing slopes than on S slopes.
8. Near center S line sec. 31, T.23N., R.44E. Road cut: 4 ft. of till on 3 ft. of laminated silt on basalt. Overlain by 1 ft. of superficial loess.

[29] Professor O. W. Freeman took a 2-foot striated argillite from this horizon. It is now on exhibit at the State Normal School.

[30] J Harlen Bretz: *op. cit.*

9. W line sec. 25, T.24N., R.43E., at intersection of side road with Palouse Highway: 3 ft. of superficial loess on 2 ft. of laminated pale silt on 8-11 ft. of till with "Palouse-soil"-like matrix, on "Palouse soil."
10. Silica-brick pit of Gladding-McBean Co., 0.5 mi. N of Mica: 4 ft. of compact loess on max. 8 ft. of till with "Palouse-soil"-like matrix, with some rubbly gravel, on thoroughly decayed silicic crystalline rock.
11. NW ¼ SW ¼ sec. 24, T.24N., R.44E. About one mile E of Mica: 1 ft. of pebbly loess on 3-7 ft. of till with "Palouse-soil"-like matrix, on thoroughly decayed pegmatitic granite.
12. NW corner sec. 1, T.23N., R.44E., at Freeman station. 9 ft. of compact loess on max. 10 ft. till with "Palouse-soil"-like matrix, on thoroughly decayed fine silicic crystalline rock.
13. On Fivemile Prairie: E ½ NE ¼ sec. 24, T.26N., R.42E. Near center W line sec. 14, T.26N., R.42E. 2 road cuts showing 18 in. of superficial loess on till with "Palouse-soil"-like matrix.
14. On Orchard Prairie: Many road cuts througout secs. 25 and 26, T.26N., R.43E. Cuts near NE corner sec. 22, and near center W line sec. 29, T.26N., R.44E.
15. On Green Bluff Prairie: Cut along W line sec. 19, T.27N., R.44E.

This till thus is more extensive than formerly reported, being exposed in many places throughout the drift-border zone between the mouth of the Spokane River and the vicinity of Mica. It is regarded by the writer as little if at all earlier in date of deposition than the rest of the drift which Bretz named the Spokane,[31] on this part of the plateau. The reasons are:

1. In every exposure except one, in which it rests on laminated silt, the till overlies either "Palouse soil" or bedrock close to abundant "Palouse soil." In every exposure examined, the matrix is closely similar to "Palouse soil" on which it rests, with the addition in places of grit consisting of small fragments of rock indigenous chiefly to the highland. It is true that megascopically the matrix has an appearance of age, but the same is true of the underlying "Palouse soil." Even where the till is thick, the profile shows no indication of chemical decay having proceeded downward from above, as would be expected of an old till weathered in place. Finally, the contact between till and "Palouse soil" in some exposures appears to be gradational, as though stones and grit had been pressed by the glacier into the plastic surface of the "Palouse soil" with little translocation of the latter.

A mechanical and microscopic analysis of two samples of the till and two of the "Palouse soil" from three localities, has been made by P. D. Krynine. The detailed results are given elsewhere.[32] The samples of "Palouse soil" consist of 85 per cent silt, 13 per cent clay, and 2 per cent

[31] J Harlen Bretz: *Glacial drainage on the Columbia Plateau*, Geol. Soc. Am., Bull., vol. 34 (1923) p. 580.

[32] P. D. Krynine: *Age of till on "Palouse soil" from Washington*, Am. Jour. Sci., vol. 33 (1937). In press.

sand. At least 75 per cent of the grains in the silt and clay fractions show considerable secondary alteration. The sand fraction consists almost entirely of ferruginous concretion-like pellets formed *in situ*. The samples of till contain fractions coarser than any in the "Palouse soil", and these consist almost entirely of fresh angular mineral grains. The sand fraction, which is the coarsest fraction in the "Palouse soil" and is there composed chiefly of ferruginous pellets, consists of the pellets mixed with fresh angular mineral grains. The fractions finer than the one containing the pellets consist of fresh rock flour, mixed with "Palouse soil" in proportions ranging from 15 to 80 per cent of the total mass of the till.

Moreover, the coarse fractions of the till consist chiefly of mineral types different from those in the "Palouse soil," whereas the minerals present in the fine fractions of the till are to a large extent identical with those in the corresponding fractions of the "Palouse soil."

These observations appear to indicate that the weathered part of the till matrix is inherited from a time prior to the formation of the till, and that the matrix itself includes much reworked "Palouse soil." This conclusion is supported by the contrasting character of two till exposures in the same area and with about the same vertical position as those already described, one in a cut on a curving road passing under a trestle of the Great Northern Electric Railway at what was formerly the corner of 16th and Havana streets, Spokane, and the other on the north slope of Orchard Prairie, in a road cut near center N line sec. 24, T.26N., R.43E. These exposures are not included in the list of exposures of "old drift" because they differ markedly from the till at Cheney. In both places the stones and grit are imbedded in a matrix of pale-gray to yellowish-white silt, identical with the Latah formation,[33] which underlies the till in both exposures. The chemical alteration of the matrix is slight, and does not appear to differ from the degree of alteration of the Latah sediments themselves. The till at these two localities, then, has a Latah-like matrix and rests on Latah outcrops, whereas the "old till" has a "Palouse-soil"-like matrix and rests generally on the "Palouse soil." The writer believes that both types of till are the product of the same glacial stage, and that in both types the matrix is the local underlying material, glacially reworked.

2. The stones in the till range in size from coarse sand grains to boulders, but most are less than 3 inches in diameter. They include some local basalt but are predominantly granites and metamorphics from the highland to the north. Although some of them are water worn, many are soled, and a few are striated. The proportion of stones to matrix varies greatly,

[33] J. T. Pardee and Kirk Bryan: *Geology of the Latah formation in relation to the lavas of the Columbia Plateau near Spokane, Wash.*, U. S. Geol. Surv., Prof. Paper 140-A (1926).

but, in general, in a given area of exposure, matrix is more bulky than are stones. The majority of the stones consisting of rock types susceptible to decomposition (chiefly granites and other rocks rich in feldspars, hornblende, biotite, but excluding quartzites and argillites) are decomposed to varying degrees, from a firm but faintly kaolinized and slightly limonitized condition to a state of complete decay. Some, however, are entirely fresh, and there appears to be no relation between degree of decay and position in the deposit. The proportion of weathered stones to fresh stones of the same rock type is no greater at the top of an exposure than at its base. Thoroughly rotten pebbles of granite resembling the "Loon Lake granite" of Weaver [34] are found side by side with clean and firm pebbles of the same type of granite, in which flashing cleavage planes on the grains of plagioclase show striations intact. Clearly, the decay took place prior to glaciation, and is not, therefore, a valid measure of post-till time. In the highland north of the plateau, many exposures of the "Loon Lake granite" and other common rock types are much decomposed beneath veneers of fresher drift, showing that glaciation failed to remove entirely the rotten surface bedrock, and that the drift might be expected to include a considerable quantity of previously decayed material.

3. Although in nearly every exposure the "old drift" is overlain by loess, this fact is not clearly significant of relative date because of local variation in thickness of the loess. As indicated in the list of exposures, the loess capping varies from less than a foot up to 9 feet, and in some instances there is considerable variation in a single exposure. Some of the factors, aside from the time factor, that determine the thickness of the loess capping have been detailed elsewhere in this paper. In an excellent analysis of the form of the "Palouse hills," Rockie [35] has stated that under favorable conditions a foot of loess can accumulate in this part of the plateau in less than 50 years. As the average thickness of loess on the till is perhaps 3 feet, it would be unsafe to use the loess for dating the till even though great allowance be made for slower accumulation prior to the beginning of agriculture in this region.

Although thickness of loess cap is of doubtful value in dating the till, mention should be made of the fact that at Localities 10, near Mica, and 12, at Freeman, the loess cap is more compact than at the other localities, and that, at Freeman, it exhibits better developed vertical jointing than elsewhere, together with slightly more limonitization near the surface than is usual. At no other place were these characters so distinct. Although it is likely that they are merely variations in a single sheet of loess, there is a possibility that they may indicate relatively greater age

[34] C. E. Weaver: *The mineral resources of Stevens County [Washington]*, Wash. Geol. Surv., Bull. 20 (1920) p. 87.

[35] W. A. Rockie: *Snowdrifts and the Palouse topography*, Geogr. Rev., vol. 24 (1934) p. 380-385.

of this loess and hence of the underlying till. The suggestion should be checked as road construction affords new exposures in this district.

The identity of the till matrix with the underlying "Palouse soil", the presence in the till of fresh stones of readily decomposed rock types, and the unreliability of thickness of the overlying loess as a criterion of age, cast great doubt on the basis for the earlier published belief that this drift is old.[36]

At localities 2 (near Davenport) and 5 (near Waukon) (Pl. 3, fig. 2), this till lies in and upon scabland tracts, in each case near the head of the tract; it postdates the fluvial erosion of at least those parts of the scablands on which it lies. Although it is clear that ice advanced over both tracts in these places, no evidence has yet been found to indicate the magnitude of the time interval between the carving of the scabland and the later encroachment of glacier ice. The two events might have occurred during a single glacial stage. However, Bretz believed that the scablands were cut during a glacial stage that postdated the "old drift."[37] If the writer's correlation of the "old drift" be correct, that belief is not tenable.

"Spokane" drift.—The second body of drift in the Cheney-Spokane district includes the bulk of the drift on the plateau. It was referred by Bretz to a glacial stage which he named the "Spokane", and considered to be more recent than the "old drift" already discussed.[38] Bryan used the term "Intermediate" for the drift of this stage.[39] Bretz described it as consisting of boulders scattered on the plateau surface, "stony till with hummocky morainic topography" on the basalt plain north of Cheney, and stratified sand and gravel, and as lacking a prominent morainal margin. He regarded the drift as relatively fresh both lithologically and topographically, but distinguished it from the Wisconsin glaciation solely on the basis of its lack of a terminal moraine, such moraines being considered a criterion of the Wisconsin ice sheets.

The boulders mentioned by Bretz are found only in the region of the "old drift," and as a group they resemble the larger stones in that drift. As stated earlier, they are believed to be stones worked out from the "old drift" chiefly by frost-heaving and washing. Detailed examination of the basalt plain north of Cheney revealed many exposures of poorly stratified gravel grading into rubbly accumulations of poorly size-sorted stones

[36] In an unpublished communication, Professor O. W. Freeman, who has visited a number of the exposures listed, in company with the writer, agrees that no feature of this till indicates that it is significantly older than the youngest drift on this part of the plateau.

[37] J Harlen Bretz: *Glacial drainage on the Columbia Plateau*, Geol. Soc. Am., Bull., vol. 34 (1923) footnote p. 588.

[38] *Op. cit.*, p. 580-586.

J H. Bretz: *The channeled scabland of the Columbia Plateau*, Jour. Geol., vol. 31 (1923) p. 647-648.

[39] Kirk Bryan: *The "Palouse soil" problem*, U. S. Geol. Surv., Bull. 790 (1927) p. 26, 42.

washed nearly free of fines, and very likely the equivalent of Bretz stony till, which was not identified by the writer.

The identity of the Spokane drift, as distinct from the "old drift" and the Wisconsin valley-train outwash, is placed in doubt by the facts that it lacks distinctive features that in themselves carry evidence of age differences, and that its character and distribution are entirely in accord with the hypothesis that it was deposited in the same stage as the "old drift," the boulders as part of the till, and the rubble on the basalt plain at the beginning of deglaciation.

Bearing of valley-train outwash on age of the drift.—The third body of drift in the Creston-Spokane district lies in the deep valleys of the Spokane River and its larger tributaries, and consists of a thick fill of outwash gravel, sand, silt, and clay, which has been dissected into terraces by the modern streams. In the vicinity of Spokane the upper limit of this fill approximates 2000 feet, and is, therefore, 400 to 500 feet lower than the drift on the plateau. It grades westward down the Spokane River into the Nespelem silt, which has been correlated with the latest glaciation of the region.[40] Its upper surface is graded to the rock threshold of the upper Grand Coulee, which implies that the upper Grand Coulee was trenched to its present depth before the fill upstream was completed.

The constituent rock fragments are fresh, but no more so than the fresher fragments in the drift on the plateau. Overlying loess is thin or confined to a surface "dirty" zone, but these facts do not seem significant of age when the coarse character of much of the fill, and its protected position in a deep canyon, are considered. More significant is the fact that the fill is not only traceable downstream into late-glacial deposits, but is also traceable upstream, far north of the Creston-Spokane district, into features recording the latest glaciation of the region to the north as well. This outwash can, therefore, be ascribed without hesitation to the latest glacial stage in eastern Washington, which has been generally referred to as the Wisconsin.

There is, however, no reliable evidence of a long time interval between the deposition of the drift on the plateau and the valley fill. If two glaciations be assumed, then a bulky outwash fill along the Spokane River system must have been deposited during the later wastage of the ice responsible for the plateau drift. This fill must have been dissected during the assumed interglacial stage, and unless it was completely reamed out, the many sections now exposed should reveal a later fill resting unconformably on an earlier fill. As no such sections have been found,

[40] R. F. Flint: *Stratified drift and deglaciation of eastern Washington*, Geol. Soc. Am., Bull., vol. 47 (1936) p. 1881.

the evidence for correlation of the valley fill with the drift on the plateau is strengthened.

Knolled and kettled stratified drift recording the presence of ice is associated with the dissected valley fill east of Post Falls, Idaho, east of Spirit Lake, Idaho, and in the Little Spokane Valley about 25 miles north of Spokane. Till rests on the valley fill just north of the northern city limit of Spokane. If the fill were regarded as related to a glaciation later than that on the plateau, these features would be taken as the minimum outer limits of the later ice. In the writer's opinion, they are more probably a record of stages of wastage during a single glaciation.[41]

Conclusion.—Three bodies of drift in the Creston-Spokane district have been discussed: (1) the till on the plateau ("old drift"), (2) the rest of the plateau drift, chiefly stratified (Spokane drift), and (3) the stratified fill in the deep valleys (Wisconsin outwash). The criteria used for age determination fail to indicate any significant difference in date of origin for these three bodies. It is possible that the drift on the plateau dates from a glaciation earlier than the one responsible for the valley fill. It is even possible that all three bodies are of different glacial ages. Such difference, however, is not demonstrated by the facts now known, which point to a single common age for them all—namely, Wisconsin.

This correlation does not imply that the scablands heading in this district are entirely the work of Wisconsin meltwater, nor that the Creston-Spokane district was not glaciated more than once. In fact, data from the scablands themselves, beyond the drift-border zone, suggest that there was more than one episode of scabland streams. Thus, there is room for one or more glacial stages prior to the Wisconsin stage.

GRAND COULEE—CHELAN DISTRICT

General statement.—In discussing the drift border in the Grand Coulee-Chelan district, the writer has stated[42] that "In the absence of more definite correlation, and following the usage of earlier writers, the latest glaciation of this region is here arbitrarily referred to as the Wisconsin." All the drift observed in this district was referred to a single glacial stage.

The deep valleys north of the plateau carry fills of stratified drift that extend far to the north. The problem of the age relation between the fills and the plateau drift is similar to the correlation problem in the Creston-Spokane district. There is not much loess on either valley fills or plateau drift. The component material of both deposits is fresh.[43] Construc-

[41] *Op. cit.*, p. 1863.

[42] R. F. Flint: *Glacial features of the southern Okanogan region*, Geol. Soc. Am., Bull., vol. 46 (1935) p. 171.

[43] There are traces of an old decayed gravel in the Hartline basin near Coulee City [J Harlen Bretz: *The Grand Coulee*, Am. Geog. Soc., Spec. Pub. 15 (1932) p. 26; *Alternative hypotheses for channeled scabland*, Jour. Geol., vol. 26 (1928) p. 331, 335], which have yielded camel bones [Kirk Bryan: unpublished communication], but the evidence is too meager to justify interpretation of this deposit as glacial, interglacial, or preglacial.

tional surface forms in the drift in both places are little modified. Further, there are no ice-margin features north of the drift border that seem notably younger than the end moraine at the drift border itself.[44] This evidence sustains the view that all the drift so far reported in this district, is referable to a single glacial stage. A map published by Bretz [45] shows an approximate position for the border of the "Spokane drift." It is important to note here that this mapping is not based on any deposits, but on the position of the head of Moses Coulee, 10 miles north of the Wisconsin terminal moraine. This coulee clearly carried much meltwater, and this flow was believed by Bretz, on evidence from other places, to antedate the Wisconsin glaciation.[46]

Relation of drift to coulees.—Drift including till partly fills a group of coulees on the plateau, the head of Moses Coulee, the Box Canyon of the Columbia River, the Omak Lake Trench,[47] and the scabland shelf west of the west wall of Grand Coulee. Gravel knolls, which may have been built under ice-contact conditions, are present on the floor of the upper Grand Coulee. As the Box Canyon and the coulees are believed to have been initiated by meltwater flowing along former ice margins, this evidence indicates ice advance over these features at some time since they were cut. In only one, however, has a record been found indicating considerable lapse of time between the latest advance and the inferred earlier glaciation. The rock floor of the Omak Lake Trench, which is interpreted as the preglacial route of the Columbia, stands about 500 feet above the floor of the Box Canyon now occupied by the river. Hence, deepening of this order has been effected since the abandonment of the preglacial route. Pitching long profiles of tributaries to the Okanogan River upstream from the Omak Lake Trench, with knickpoints at about 500 feet vertically above the Okanogan, may possibly record this former profile. Enough time may have been required, for the erosion involved, to justify the view that the preglacial route was abandoned in consequence of a glaciation that preceded the latest one.

Thus, the correlation question is on the same footing in the Grand Coulee-Chelan district as in the Creston-Spokane district, in that the evidence of pre-Wisconsin glaciation is at present indirect and unsatisfactory.

HIGHLAND DISTRICT

The Creston-Spokane district is tied to the Grand Coulee-Chelan district by a nearly continuous drift border across the highland, in which the

[44] North of the end moraine, certain faint ridges that may themselves be miniature recessional-moraine features, have been recorded by A. C. Waters [*op. cit.*, p. 785], but no evidence has been found in them to indicate that they date from a glacial stage younger than the one with which the outer end moraine is correlated.

[45] J Harlen Bretz: *The channeled scabland of eastern Washington*, Geogr. Rev., vol. 18 (1928) pl. 5.

[46] J Harlen Bretz: unpublished communication.

[47] R. F. Flint: *op. cit.*, p. 175-177.

glacial features differ from those on the plateau. However, the drift in the highland has furnished thus far no criteria for age-correlation. The till in the valleys commonly has a matrix grayer in color and more gritty in texture than the till on the plateau, but this is believed to be a reflection of the highland lithology. In every exposure seen by the writer thus far, the till is fresh from top to base. At high elevations the scattered glaciated stones are preponderantly fresh and, therefore, indicate no very remote date of origin. The distribution of these stones, however, may be significant. The long profile of the upper surface of the ice, inferred from the elevations of the stones at many points, appears to be a single unit, and no concentration of till or erratic stones has been found at lower levels, which would indicate the margin of a later and thinner glacier. This evidence, so far as it goes, suggests that the deposits are referable to a single glaciation. Pardee[48] mentions "two levels of glaciation" on the east flank of the Kettle Range at Twin Lakes, at the head of the Nespelem River, and on the east slope of the Sanpoil Valley at Bridge Creek. At the first locality, the higher level is the approximate upper limit of the drift, consisting chiefly of erratic stones on the mountain sides. The lower level is marked by an extensive deposit of stratified gravel and sand at Twin Lakes, termed by Pardee a lateral moraine, but believed by the writer to be a local constructional terrace or embankment, one of several in this region, built at the lateral margin of the Columbia lobe during deglaciation. This deposit, like the erratic stones at higher elevations, consists of fresh material, and does not in itself indicate a second stage of glaciation. The deposit at the head of the Nespelem consists of gravelly drift, likewise fresh, and, although it indicates a deposit near an ice margin, possibly following a readvance, no evidence was found to suggest correlation with a glacial stage younger than the one recorded by the upper limit of the drift in this latitude. The exact nature of the evidence at the Sanpoil Valley locality is not made clear by Pardee. Perhaps the contrast between ice-abraded lower slopes of Mt. Chilimas, in secs. 4 and 5, T.31N., R.33E., and the little-abraded or non-abraded upper slopes, which, nevertheless, carry a few erratics, was meant. If so, the contrast does not, in the writer's opinion, constitute evidence for or against two distinct glacial stages.

AGE CORRELATION BETWEEN CRESTON-SPOKANE DISTRICT AND GRAND COULEE-CHELAN DISTRICT

In the three districts discussed, there is direct evidence of comparatively late Pleistocene glaciation. In the district west of the Grand Coulee, this glaciation has been generally assigned to the Wisconsin stage. As noted earlier, Bretz differentiated the Wisconsin drift in the Grand

[48] J. T. Pardee: *Geology and mineral deposits of the Colville Indian Reservation*, U. S. Geol. Surv., Bull. 677 (1918) p. 52.

Coulee-Chelan district from the "Spokane" drift in the Creston-Spokane district solely on a basis of "the moraine-building habit of the Wisconsin ice sheet."[49] This basis of differentiation may be questioned on the ground that unit drift borders elsewhere in North America and in Europe have end moraines in one sector and not in another sector, showing that a single glacier margin changes its character and habit of deposition from place to place.

In this connection, it must be repeated that although Bretz' 1928 map distinguishes between the limit of Wisconsin ice and the approximate limit of Spokane ice farther north, this discrimination was based, not on the presence of two drift bodies, but on the fact that the head of Moses Coulee, draining south, scoured by glacial meltwater, extends about 10 miles northward back into the area covered by Wisconsin ice, thereby implying an ice front north of the Wisconsin drift border.

No reason other than end-moraine-building habit has been suggested for regarding the plateau drift in the Creston-Spokane district as older than the plateau drift in the Grand Coulee-Chelan district. True, the till on the plateau in the Grand Coulee-Chelan district is paler in color and includes a smaller proportion of decayed material than the till described from the Creston-Spokane district. However, this difference does not compel the view that the deposits are of different dates. The composition of any drift body is likely to change laterally with changing source material. An extreme example is the change in the latest drift encountered in passing from the western Great Lakes region to New England. Here the change is less marked, but it may be in part owing to the presence, in the Grand Coulee-Chelan district, of pale-gray silt and sand having the general stratigraphic relations of the Latah formation, and also to relatively greater contributions to the till, of rock flour from the highland rocks north of the plateau.

The only nearly continuous features common to both districts are the valley fill, which, unfortunately, is not directly traceable into the plateau drift in either district, and the drift border. The apparent unity of the latter, together with the essential freshness of the drift itself, makes it probable that the peripheral drift throughout the entire region is of this age.

Although the evidence of pre-Wisconsin glaciation is indirect, it has been shown that the relation of the drift to coulees and to scabland features does not exclude the possibility of one or more pre-Wisconsin glaciations.

---

[49] J Harlen Bretz: *The channeled scablands of the Columbia Plateau*, Jour. Geol., vol. 31 (1923) p. 648; *The channeled scabland of eastern Washington*, Geog. Rev., vol. 18 (1928) pl. 5 (facing p. 476).

AGE CORRELATION WITH OTHER REGIONS

Although no old drift weathered *in situ* has been found in eastern Washington thus far, old drift has been reported from neighboring regions. In the Bitterroot Mountains, Russell found records, based on degree of weathering, of three stages of valley glaciation, of which the middle and latest were closely related in time.[50] Ross reports two stages of glaciation in south-central Idaho.[51] In the Puget Sound region, Willis has described two drifts separated by interglacial beds.[52] Johnston has reported evidence of two glacial stages in British Columbia, separated by a considerable time interval, during which bedrock was eroded to depths of several hundred feet.[53]

According to these facts, it is likely that there was earlier glaciation in eastern Washington, which at any rate could scarcely have escaped glaciation that affected regions lying immediately east and west of it. That no earlier drift has been recognized beyond the limits of the drift described in this paper, may be due to (1) greater nourishment of the later ice, possibly as a result of mountain uplift during interglacial time, or (2) scour during earlier glaciation, which prepared paths that increased the efficiency of the later ice, permitting it to overlap completely the earlier drift.

The freshness of the drift in eastern Washington and the preservation of its constructional topography indicate correlation with the Wisconsin drift of eastern Montana. More nearly direct evidence comes from the Willamette Valley in western Oregon, where Allison has reported deposits made by streams of meltwater that had passed through the scablands in eastern Washington. Several lines of evidence suggest a date for these deposits equivalent to some part of the Wisconsin stage of the Mississippi Valley region.[54]

CHARACTER OF THE GLACIER

The configuration of the upper surface of the ice is restored from the upper limit of drift on the sides of ranges and smaller nunataks. The reading at any one point gives a minimum figure for the former ice surface, which, in some places at least, stood considerably above the highest recorded drift. This is shown by observations made close together along the flank of a single range, which do not record a consistent northward

[50] Jeanne Russell: *Glaciation in the Bitterroot Mountains of Montana* (abstract), Geol. Soc. Am., Bull., vol. 37 (1926) p. 218.

[51] C. P. Ross: *Geomorphology of south-central Idaho* (abstract), Geol. Soc. Am., Pr., 1934 (1935) p. 103.

[52] Bailey Willis: *Drift phenomena of Puget Sound*, Geol. Soc. Am., Bull., vol. 9 (1898) p. 141-153.

[53] W. A. Johnston: *The Pleistocene of Cariboo and Cassiar districts, British Columbia, Canada*, Royal Soc. Canada, Tr., Sec. 4 (1926) p. 142-145.

[54] Ira S. Allison: *Glacial erratics in Willamette Valley*, Geol. Soc. Am., Bull., vol. 46 (1935) p. 627-631.

rise of the highest drift features. Observations made farther apart, however, show such a rise, and in restoring the upper surface of the ice, low figures between two higher ones along a north-south line are neglected.

Figure 1 is an attempt to restore the upper surface of the ice by contours spaced 500 feet apart. It is based on the assumption that the drift features record the trace of a single ice surface, rather than parts of two

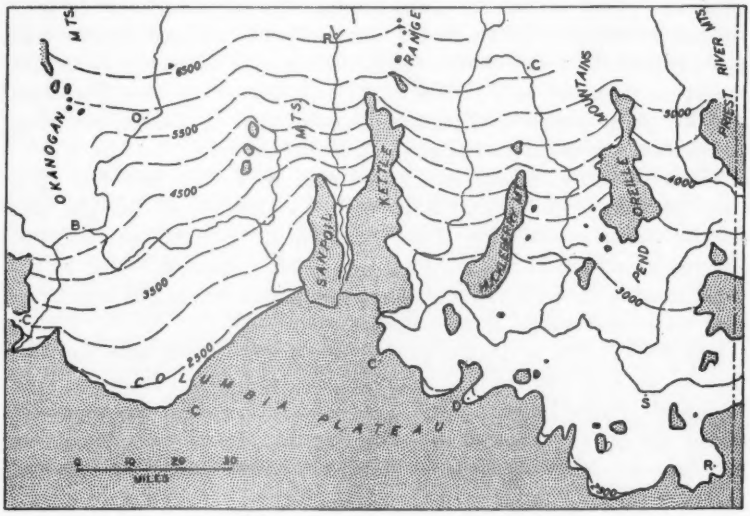


FIGURE 1.—*Upper surface of glacier at its maximum*

Restored by contours (interval 500 feet). Contouring generalized.

or more ice surfaces of different dates. Even on this assumption the picture is necessarily generalized, and no accuracy of detail is claimed for it. The trend of the contours between two nunatak areas is not based entirely on interpolation, as glaciated high points on the intervening ground give minimum figures for those points; and where striae are present on them, the contours are drawn normal to the striae. The broad curves shown in the western part of the region are, however, based only on their inferred parallelism with the drift border.

Serrate peaks rising above drift-covered subsummit areas did not necessarily stand higher than the highest ice surface, as frost weathering may have modified them following maximum glaciation.

The record shows the ice to have had a concave-up profile measured in directions from its sources toward its southern margin. In the eastern

part of the region the slope is about 15 feet per mile [55] for 35 miles, increasing to about 100 feet per mile in places where the ice was crowded between ranges and hence moved relatively rapidly, and decreasing to 50 feet per mile or less in the region north of the nunatak areas. In the western part of the region the slope is about 50 feet per mile near the southern margin, increasing gradually to nearly 100 feet per mile south of the Okanogan Mountains. The slopes may have been originally somewhat less, owing to their steepness having been increased by postglacial crustal upwarping. These figures compare with a rough figure of 75 feet per mile [56] for the surface slope of Malaspina Glacier, a somewhat analogous piedmont bulb in Alaska. The surface slope on a Wisconsin ice lobe under comparable topographic conditions in Yukon, according to Bostock, was about 16 feet per mile for 80 miles.[57]

The ice at its maximum would have been more than 5000 feet thick over the site of the Columbia River in the latitude of Colville, and slightly thicker over the site of the Okanogan River in the same latitude. Figures on the thickness of the ice are of little value, however, as the great relief of the region over which the ice flowed resulted in very irregular thicknesses within short distances.

The drift border is doubly lobate, lying farther south near the west base of the high Rockies and near the east base of the Cascades, than in the intervening lower country. The lobation is caused in part by the Kettle Range, which parted the advancing ice. If, however, the glacier had been nourished primarily by direct precipitation upon its own surface, after the manner of an ice sheet, the highest part of the ice surface should have lain about midway between the high Rockies and the Cascades, and the drift border should be singly lobate, reaching farthest south in the district between Creston and the Grand Coulee. The concave-up form of the ice surface in long profile, and the doubly lobate form of the drift border, indicates that the ice was of the piedmont type, fed by lateral valley glaciers originating in the high Rockies and in the Cascades, and Coast Ranges of British Columbia. The inefficiency of glacial erosion in the marginal zone, especially in that part of the region lying between the Kettle Range and the Washington-Idaho line, is probably attributable to the pool-like expansion of the piedmont glacier as compared with the smaller but more efficient valley glaciers that fed it.

[55] This figure may be somewhat too low, as the upper surface of the ice in the Creston-Spokane district is much less distinctly recorded than it is farther north. However, a modern counterpart in Muir Glacier, Alaska, with a surface slope of 17 feet per mile, is reported by W. S. Cooper [*The problem of Glacier Bay, Alaska: a study of glacial variation*, Geog. Rev., vol. 27 (1937) p. 43].

[56] I. C. Russell: *Second expedition to Mt. St. Elias*, U. S. Geol. Surv., 13th Ann. Rept., pt. 2 (1893) p. 20.

[57] H. S. Bostock: *Carmacks district, Yukon*, Geol. Surv. Canada, Mem. 189 (1936) p. 11.

Ineffective glacial erosion in the marginal zone is shown by a number of features. The stream-dissected slopes inherited from the preglacial condition are only slightly modified, and differ little from slopes on similar rock types outside the glaciated region. Exposures of ice-abraded bedrock are very scarce, and exposures of thoroughly rotten bedrock are plentiful. Toward the north this condition changes gradually, giving way to slopes in which the smaller stream furrows cut by preglacial runoff have been obliterated, with many exposures of fresh bedrock strongly scoured by ice. The same transition may be seen in a vertical direction, with glacially modified valley floors and lower slopes, rising into little modified higher slopes scantily covered with drift.

It has been shown that the ice in the Creston-Spokane district was thinner, had a more gently sloping upper surface, and had a margin much more lobate in detail than the ice in the Grand Coulee-Chelan district. This agrees with the lack of end-moraine development here, and with the apparently gentler north-south slope of the upper surface of the ice, and seems to indicate relatively feeble and ineffective ice movement.

The ice came chiefly from sources in British Columbia, although lateral tributary glaciers originated in the Selkirks and other ranges in Idaho. Valley glaciers, originating in the Cascade ranges to the west, also occupied the Methow and Chelan valleys. Russell [58] mapped the Chelan valley glacier as coalescent with the Okanogan lobe at Chelan, and Waters [59] stated that the Okanogan ice flowed a short distance up the Chelan valley, but he did not specify the time of such flow relative to the glacial maximum. Russell mapped the Methow valley glacier as failing to connect with the Okanogan lobe. Reconnaissance observations by the writer seem to indicate that during the glacial maximum this was not the case, and Daly [60] has reported much thicker ice north of the head of the Methow valley than had been indicated by Russell. However, the matter is not settled and must await further study.

In eastern Washington, some of the high nunatak summits are frost-sharpened, and rudimentary cirques are present in the northeast face of Calispell Peak in the Pend Oreille Mountains, at 5800 feet, and in Hooknose Mountain, northwest of Metaline Falls, at a slightly higher altitude. The elevations of the cirques are a rough measure of the snowline at the time the cirques were formed, presumably at or near the glacial maximum. A comparison of these elevations with the present snowline in the

[58] I. C. Russell: *Geology of the Cascade mountains in northern Washington*, U. S. Geol. Surv., 20th Ann. Rept. (1900) p. 161, 166, pl. 18.

[59] A. C. Waters: *Terraces and coulees along the Columbia River near Lake Chelan, Washington*, Geol. Soc. Am., Bull., vol. 44 (1933) p. 807 and references there cited.

[60] R. A. Daly: *Geology of the North American Cordillera at the forty-ninth parallel*, Geol. Surv. Canada, Mem. 38 (1912) p. 594; pl. 49.

high Rockies in northern Idaho and Montana indicates a Pleistocene snowline about 3000 feet lower than the present snowline. Allowance for the former lower stand of this part of the crust under the depressing influence of ice load would, however, reduce the snowline elevation by an unknown amount. The difference in present precipitation between the mountains of northeastern Washington and the high Rockies, although not great, would likewise alter the figure somewhat. Detailed study of the abandoned cirques in the high ranges of the Cascades and of northern Idaho should yield much evidence on the snowline of the glacial maximum.[61] The fact that the Pleistocene depression of the snowline appears to have been greater in the Cascades and Coast Ranges than in the high Rockies is harmonious with the evidence given, that, in eastern Washington, ice movement from the northwest was more vigorous than movement from the northeast.

CRUSTAL WARPING UNDER GLACIAL LOADING

During the field work, effort was made to find bases for measurement of crustal warping that might be related to loading by Pleistocene ice. In the upper Grand Coulee, the surface of the Nespelem silt, a lacustrine deposit presumably initially nearly horizontal, rises northward at a rate of approximately 5 feet per mile,[62] and may record warping of this character. The thick lacustrine fills in the southern part of the Sanpoil Valley and in the Columbia trench above the mouth of the Spokane also rise northward, but the upper parts of their sections are in part fluvial, and, therefore, it has not been possible to distinguish between initial depositional slope and inclination due to warping. The Clark Fork trench north of Newport carries a rather thin fill of laminated silt related to a late-glacial lake whose level was controlled by a threshold at Newport. As the upper surface of the fill is little complicated by fluvial deposits and rises slightly northward, precise measurements on it may yield a minimum measure of postglacial warping in this district. The figure reached by this method cannot be exact, however, as shoreline features are lacking, and the exact position of the former lake surface has not been fixed.

The lack of suitable data for the measurement of crustal warping is particularly disappointing, as, with the thickness and areal extent of the ice fairly well known, an independent determination of the related crustal basining would yield geophysical results of considerable value.

---

[61] *See* Herbert Louis: *Die Verbreitung von Glazialformen im Westen der Vereinigten Staaten*, Zeitschr. für Geomorphologie, vol. 2 (1926-1927) p. 221-235; pl. 4.

[62] R. F. Flint: *Glacial features of the southern Okanogan region*, Geol. Soc. Am., Bull., vol. 46 (1935) p. 189.

PROGLACIAL DRAINAGE NEAR THE DRIFT BORDER

The plateau surface is marked by a number of areas of denuded basalt, described by Bretz as scabland.[63] Bretz showed these areas to have been cut by streams of water that originated in or north of the ice margin. He believed the streams to have been contemporaneous and of enormous volume, constituting the "Spokane flood", and imparting a catastrophic character to the episode or episodes of scabland erosion.

The writer has gathered a considerable body of facts bearing on the genesis of the scablands. These will be the subject of a later publication. From a study of the scabland channel heads at and near the drift border, it may be concluded that:

1. There was opportunity for two or more episodes of glacial drainage across the plateau.

2. No evidence has been found in any tract east of the Grand Coulee that would indicate the operation of any except normal proglacial streams.

ACKNOWLEDGMENTS

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[63] *See the papers already referred to, especially The channeled scabland of eastern Washington,* Geogr. Rev., vol. 18 (1928) pl. 5.

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W. H. Bartlett *C. Cousen*

TRENTON HIGH FALLS
From a lithograph, published in London in 1838.

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STRATIGRAPHY OF THE TRENTON GROUP

BY G. MARSHALL KAY

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INTRODUCTION

A century ago, on April 15, 1836, the formation of a "geological survey of the State of New-York" was authorized by its legislature. Timothy Conrad began field work the following June in the Mohawk Valley, describ-

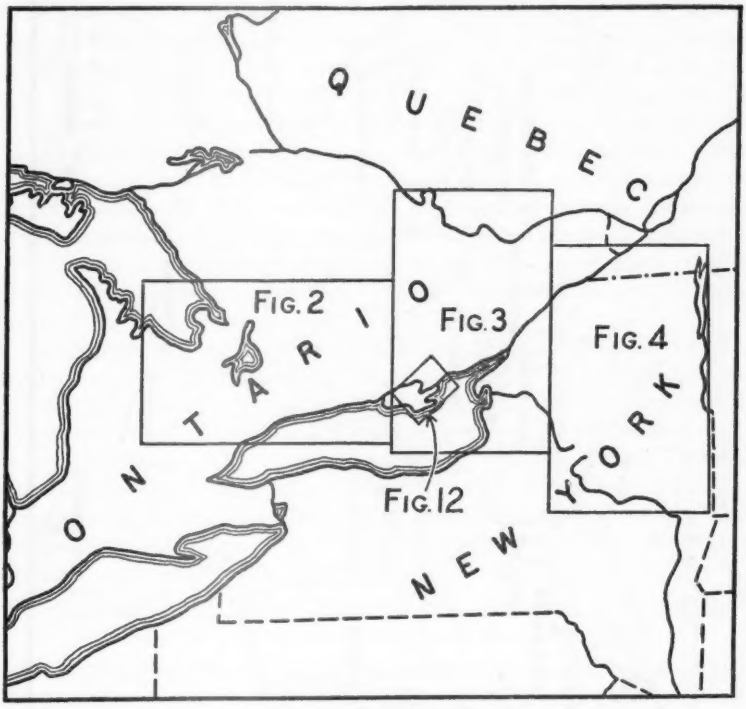

FIGURE 1.—*Index to locality maps*

ing in his first report the "Blue Foetid Limestone and Shales of Trenton-Falls." It is the present purpose, first, to review the study of these sediments prior to Conrad's naming them and trace the developments during the century that has followed; second, to define and give brief descriptions of the subdivisions of the Trenton group, the upper part of the Mohawkian series of the Ordovician system; finally, to summarize interpretation of the distribution and changes in the sediments.

The writer has studied the Trenton group for a number of years; a grant from the Penrose Bequest of the Geological Society permitted re-study of the entire problem during the summer of 1935. The fauna of the group

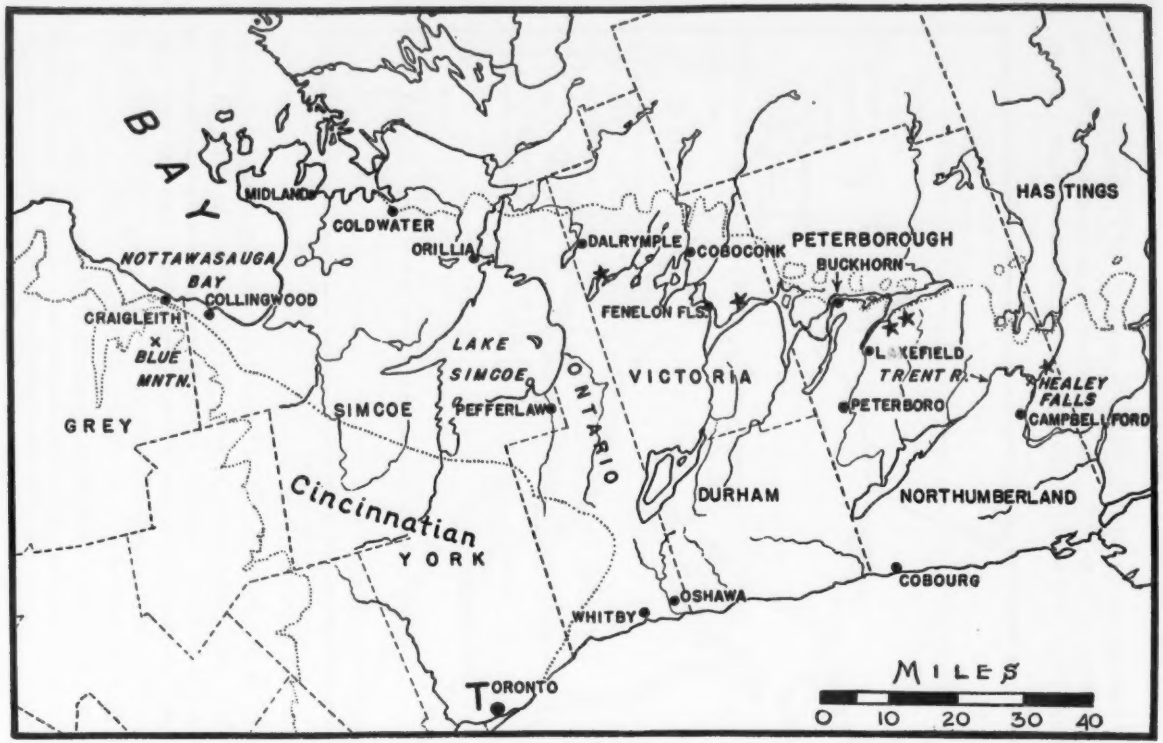

FIGURE 2.—*Localities in Ontario*
See Figure 1.

is very large; only the significant facts concerning its species will be included in the succeeding pages.

The Mohawkian series crops out in several regions in New York and Ontario (Pl. 5 and Fig. 1). The continuous belt from Trenton Falls through northwestern New York and southern Ontario includes the typical Trenton limestone; the essential structure is homoclinal, with beds dipping toward Lake Ontario from the crystallines of the Adirondack Mountains and central Ontario. Northeastward, beyond the Frontenac Axis, lies the Ottawa Valley region, stratigraphically similar to the last mentioned. Its basin structure is modified by a fault system that extends northwestward, the upper Ottawa Valley graben including Trenton outliers. Eastward, the region is isolated from the Ordovician north of the St. Lawrence River, between Montreal and Quebec, by Cambrian outcrop connecting the Adirondacks with the Canadian Shield. This area has faults paralleling the contact with the crystalline rocks to the north, and others related to Adirondack structure; it is bounded southeastward by the great Taconic thrusts.

In the region of the lower Mohawk Valley and Lake Champlain, south and east of the Adirondacks, the thrusts again form the eastern limit of Mohawkian outcrop. The area belongs stratigraphically in a province in which the Trenton is predominantly shale in contrast to the limestones of the other regions. The area is contiguous with the typical Trenton limestone region of the upper Mohawk Valley, this belt of lithologic change being further complicated by a series of transverse faults. The early geologists began their studies in this confused area, and their difficulties are readily understandable.

HISTORY OF CLASSIFICATION OF THE MOHAWKIAN SERIES

CLASSIFICATION OF AMOS EATON (1820–1830)

The first classification of the Ordovician rocks in the valley of the Mohawk River was made by Amos Eaton, who followed the Wernerian arrangement. "I shall adopt the following theory. That at the creation, the materials constituting the earth were finely comminuted and mixed with water, so as to form the chaotic paste. That these materials united together by attraction of cohesion or aggregation, and settled down towards the center in layers arranged nearly in the order of their specific gravities."[1] "The recent custom among geologists of cutting up and subdividing, seems to be upon the point of ruining the simplicity of the Wernerian arrangement." The "names were constructed upon the principle . . . of compounding the name of the most important mineral embraced in the rock, with an adjunct expressing to bear."[2]

[1] Amos Eaton: *An index to the geology of the northern States* (1820) p. 13. Troy.

[2] Amos Eaton: *A geological and agricultural survey of the district adjoining the Erie canal, in the State of New York* (1824) p. 17-19. Albany.

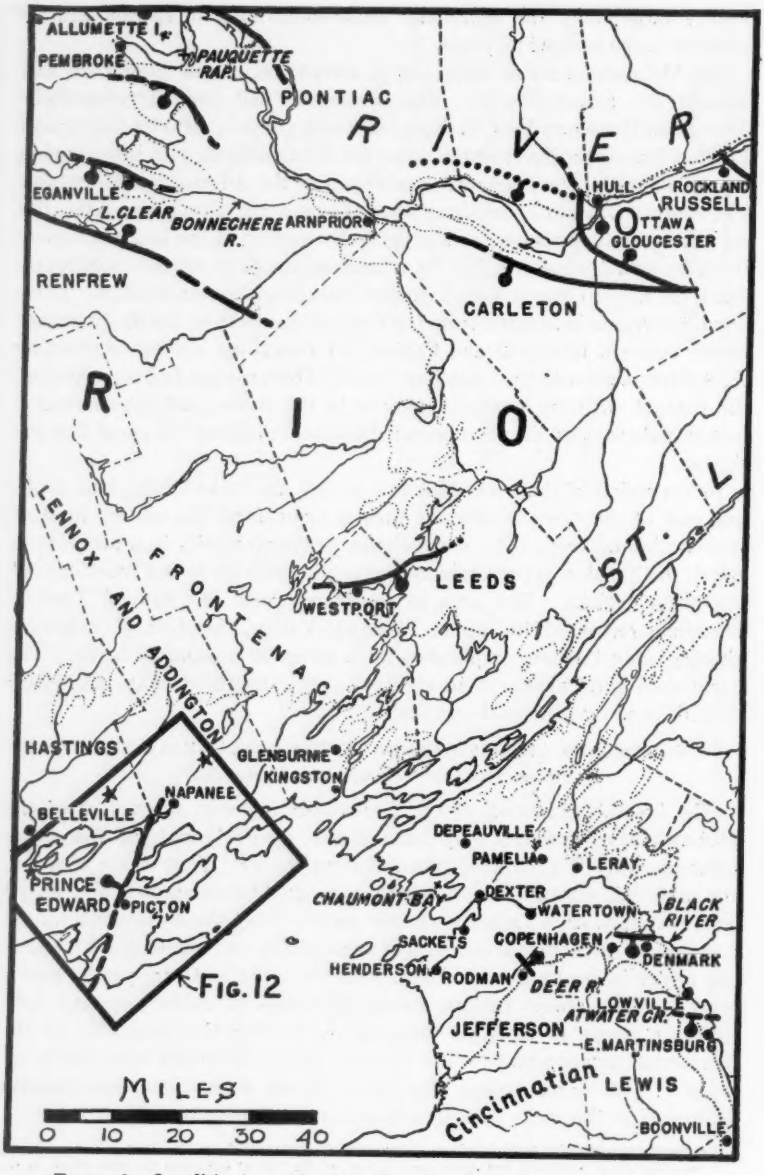

FIGURE 3.—*Localities in southeastern Ontario and northwestern New York*
See Figure 1.

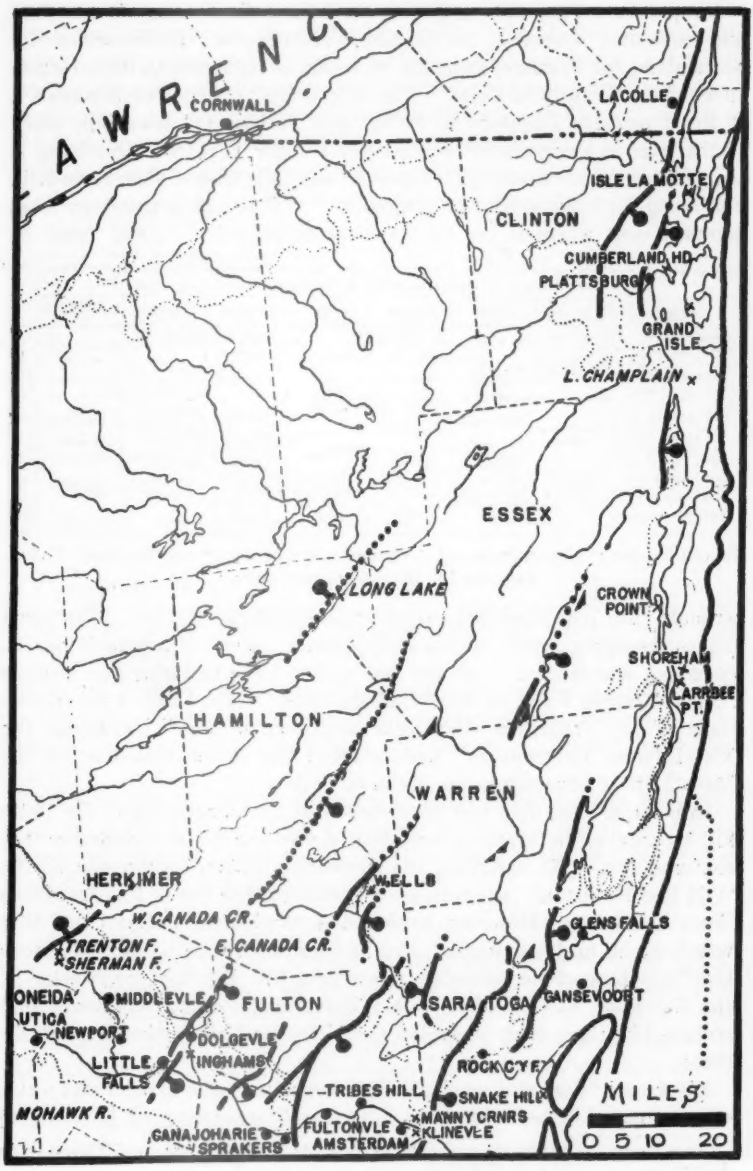

FIGURE 4.—*Localities in eastern New York*
See Figure 1.

Eaton followed this plan in placing the rocks in the Primary, Transition, and Secondary classes of the existing nomenclature. He described the rocks above the Primary, along the Mohawk, as belonging to three formations of the Transition Class.[3] The oldest, the "Calciferous Sandrock", is the magnesian limestone of "Flint Hill in Florida" township, south of the river in easternmost Montgomery County (Fig. 5). Overlying is the "Metalliferous Limerock", exposed "one mile east of Schoharie-Kill, and along the ledge south of Canajoharie." "This rock is generally most compact near where it lies on the stratum below," . . . and "may be

CLASSIFICATION OF MOHAWKIAN ROCKS IN THE MOHAWK VALLEY, NEW YORK

	MOHAWK VALLEY FORMATIONS	EATON 1820–1830	CONRAD 1837	VANUXEM 1838	CONRAD 1839	VANUXEM 1842	HALL 1843	PROSSER AND CUMMINGS 1900	
SIL.	ONEIDA	Millstone Grit		Millstone Grit of Prof. Eaton		ONEIDA CGL.	ONEIDA GRIT		O.
CIN.	FRANKFORT	Graywacke	Blue Fœtid Limestones and Shales of Trenton Falls	Green shale	Green slate	FRANKFORT SL.	UTICA SLATE	HUDSON RIVER SHALE	F.
MOHAWKIAN TRENTON	UTICA			Black shale	Trenton limestone and slate	UTICA SLATE		UTICA SHALE	U.
	CANAJOHARIE								C.
	Shoreham or GLENS FALLS Lorraine	Metalliferous Limerock		Trenton Limestone		TRENTON LIMESTONE	TRENTON LIMESTONE	TRENTON LIMESTONE	B.P.
	AMSTERDAM		Gray Sparry Limestone of Mohawk Valley		Mohawk limestone	Base of the Trenton ls.		BLACK RIVER LS.	A.
BLD.	LOWVILLE			Birdseye		Birdseye	BIRDSEYE	BIRDSEYE	L.
B'K'N.	TRIBES HILL	Calciferous Sandrock	Bastard ls.	Calciferous Sandrock	Gray ls. with sparry veins	Fucoidal Layers	CALCIFEROUS SANDROCK	CALCIFEROUS SANDROCK	T.H.
CAM.	LITTLE FALLS		Calcareous Ss. Mohawk Valley		Gray calcareous sandstone	Calciferous Sandrock			L.F.
PRE-C.	PRE-CAMBRIAN		Gneiss	Gneiss	Primary	PRIMARY			pC.

FIGURE 5.—*Early classifications of Mohawkian sediments in the Mohawk Valley, compared to the present classification*

wrought into that beautiful variety called birdseye marble." "In some places the upper layers of this rock contain numerous petrifactions. A collection was made . . . at the east end of Lake Ontario; and another . . . at Trenton Falls, on West-Canada Creek." The third of the formations of his Transition Class was described as the "Graywacke (or Metalliferous Graywacke)" and included the shales that succeed the Metalliferous Limerock in the Mohawk Valley.

In incorporating the "vast graywacke district connected with the Catskill Mountains" in this third formation, Eaton was led into anomalies that confused him. He described the succeeding Catskill sediments as the "Old Red Sandstone", the formation considered the top of the Transition Class in Europe. However, he found a conglomerate near Utica that was lying on his "graywacke", and he considered it to be the "Millstone Grit", the base of the Secondary Class (Fig. 6). But the "graywacke" of the Catskills, which he had called Transition, overlay limestones that seemed like those that succeeded the Millstone Grit farther west in the State.

He wrote: "I am still much at a loss respecting some of the rocks which were examined in the Helderberg. The cornitiferous limerock [Onondaga]

[3] Amos Eaton: *A geological and agricultural survey of the district adjoining the Erie Canal, in the State of New York* (1824) p. 12, 32-33, 72-92.

is certainly the same rock which embraces Bethlehem cavern, twelve miles south of Albany. Several other rocks of the Helderberg perfectly agree in every character with some of those which overlay the secondary rocks of the west. Shall we say that these rocks are wanting in the Helderberg series? Do not the limerocks about Hudson and Catskill belong to the transition class, overlay transition sandstone, and pass under the Catskill Mountain graywacke?" [4] Six years later, he thought that "in

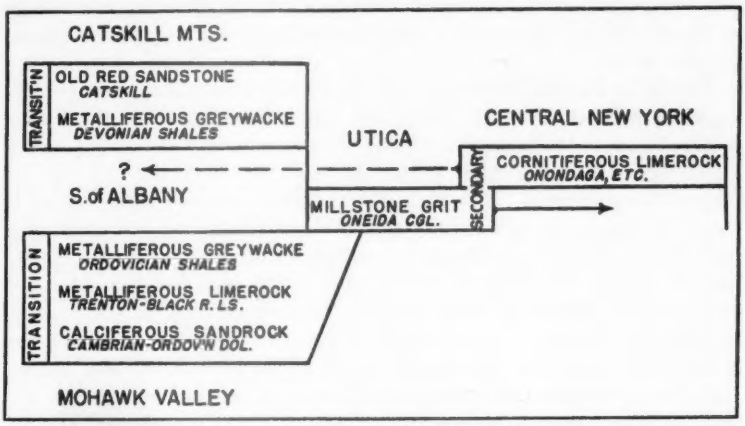

FIGURE 6.—*Terms applied by Amos Eaton, 1820-1830, to the sediments south of the Mohawk Valley*

the midst of these splendid discoveries, which overwhelm the strongest imagination with wonder and amazement, some reformation seems to be required; even among those rocks where Lehman and Werner begun their labors." [5]

It remained for a group of younger men, unencumbered by the Wernerian doctrine, to bring a more orderly arrangement to the rocks of New York. Eaton had outlined a sequence in the Ordovician of the Mohawk Valley that was to serve as a beginning.

GEOLOGICAL SURVEYS OF NEW YORK AND CANADA (1836–1863)

At the formation of the "geological survey of the State of New-York" in 1836, Timothy Conrad was assigned to the Third District, including most of the Mohawk River valley. The first report of his field work, which began about June 1836, was published in the following year.[6] It was natural that he should have begun his studies at the base of the

[4] *Op. cit.*, p. 84-96.

[5] Amos Eaton: *Geological textbook* (1830) p. 14. Albany.

[6] T. A. Conrad: *First annual report on the geological survey of the third district of the State of New York*, N. Y. Geol. Surv., 1st Ann. Rept. (1837) p. 155-186.

sedimentary sequence, in the more populous area adjacent to the Erie Canal, where Eaton had outlined the section.

The Calciferous Sandrock was subdivided, the "Calcareous Sandstone of the Mohawk valley" being its lower part. The upper beds were designated the "Bastard Limestone", a name that had been recorded by Eaton.[7] The Metalliferous Limerock was reclassified, the lower beds being called the "Gray Sparry Limestone of the Mohawk Valley", abbreviated in a subsequent report to "Mohawk Limestone";[8] this was also referred to as Eaton's Sparry Limerock, a term that had included a variety of stratigraphic units.

The "Blue Foetid Limestones and Shales of Trenton Falls" succeeded, "dark blue limestones and shales, the whole mass probably about four hundred feet in thickness, composing the summits of most of the slopes which descend to the valley of the Mohawk, in Herkimer and part of Montgomery counties. The rock is here chiefly a fissile slate, but as it passes to the north, it assumes, as at Trenton-Falls, the character of a dark blue very hard foetid limestone, crowded with organic exuviae, chiefly bivalve shells and fragments of trilobites. The rock has here been cut through by a branch of West Canada creek, which thus, in a succession of beautiful cascades, leaps through a deep gorge between perpendicular black walls. The wild grandeur of the scene has given it peculiar attractions for the fashionable tourist, and the organic remains will always add an additional charm to the spot, in the estimation of a geologist" (Pl. 1). Thus, the upper part of the Metalliferous Limerock and the Graywacke became the Trenton.

Conrad had believed the shaly limestones of Trenton Falls to be equivalent to the shales of the Mohawk Valley. The interrelations of facies and faunas were suggested in a later statement:[9] "It is remarkable that the Caradoc rocks should consist of sandstone in Wales, whilst the Trenton limestone and slate form so prominent a feature of the series in this country. Had it been otherwise, a more extended correspondence would probably have occurred between the fossil groups on each side of the Atlantic." Stratigraphy had made great advances in the decade.

"This [Trenton] rock is developed in its greatest thickness in the north-eastern portion of Oneida county, gradually thinning out and disappearing in its southeastern prolongation. North of Trenton-Falls there is a capping of gray crinoidal limestone."[10] The next year, Conrad

[7] Amos Eaton: *A geological and agricultural survey of the district adjoining the Erie canal, in the State of New York* (1824) p. 75. Albany.

[8] T. A. Conrad: *Second annual report on the paleontological department of the survey*, N. Y. Geol. Surv., 3d Ann. Rept. (1839) p. 63.

[9] T. A. Conrad: *On the Silurian system, with a table of strata and characteristic fossils*, Am. Jour. Sci., vol. 38 (1840) p. 88.

[10] T. A. Conrad: *First annual report on the geological survey of the third district of the State of New York*, N. Y. Geol. Surv., 1st Ann. Rept. (1837) p. 164.

classified the last as the "Gray crinoideal limestone," of the "Group of the Trenton limestone," calling the underlying beds above the Mohawk limestone the "Trenton limestone and slate" [11] (Fig 7).

In 1837, Conrad became paleontologist of the survey, and Lardner Vanuxem continued the work in the third district. In removing the black shale of the Mohawk Valley from the original Trenton,[12] he introduced an interpretation that persisted erroneously for the rest of the century. In his final report,[13] the rocks of Ordovician age were placed in the Champlain division of the New York System, the Potsdam sandstone

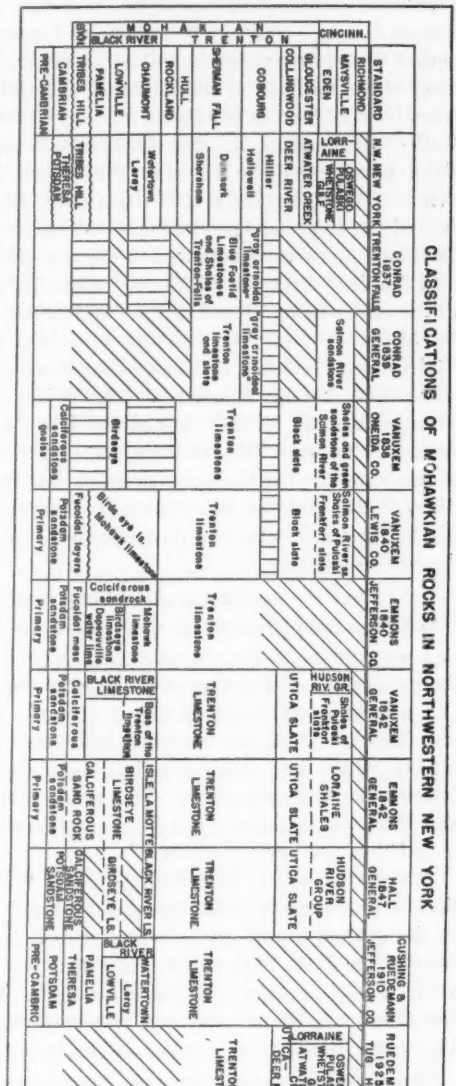

FIGURE 7.—*Early classifications of Mohawkian sediments in northwestern New York, compared to the present classification*

[11] T. A. Conrad: *Second annual report on the paleontological department of the survey*, N. Y. Geol. Surv., 3d Ann. Rept. (1839) p. 63.

[12] Lardner Vanuxem: *Second annual report of so much of the geological survey of the third district of the State of New York as relates to objects of immediate utility*, N. Y. Geol. Surv., 2d Ann. Rept. (1838) p. 255.

[13] Lardner Vanuxem: *Geology of New York. Part III, comprising the survey of the third geological district* (1842) p. 24-60. Albany.

(Cambrian) forming the base of that division. Above the succeeding "Calciferous Group," was the "Black River Limestone" group; "this term is applied to the first range or cliff of limestone on Black River, . . . composed of the birdseye of the Mohawk, and the rock upon which the well-characterized Trenton limestone, in many of its localities is placed." "The Black-river limestone has at its base or foot the primary rocks." Above the Black River came the "Trenton Limestone, Metalliferous Limerock of Eaton." The next group is the "Utica slate. Black slate or shale. Fairfield slate of the Reports. Greywacke, or Metalliferous Greywacke of Eaton." The Frankfort slate was placed in the succeeding "Hudson River Group."

In the final report of Emmons,[14] a similar classification was followed, all the strata being placed in the "Champlain Group" of the "New-York Transition System", the former including the "Potsdam sandstone", "Calciferous Sandrock", "Chazy Limestone", and "Birdseye Limestone" below the "Trenton Limestone" and "Utica Slate". In his description, he segregates the "Black Marble of Isle La Motte" as "an important mass . . . between the Birdseye and Trenton limestone. . . . A similar mass, occupying the same position, has been wrought many years at Glens Falls" and "at Watertown in Jefferson county, the banks of the Black River are formed of the same rock. It is known by quarrymen as the Seven-foot tier."

CLASSIFICATIONS OF JAMES HALL (1842–1847)

With the completion of the field reports of the geological survey, attention was turned to the paleontology, prepared by James Hall. Prior to the publication of the first of the paleontologic reports, Hall [15] expanded Conrad's Mohawk limestone to a group rank: "In New York we have . . . the limestone along the Mohawk valley, . . . the "Mohawk limestone", a name which with much propriety might be applied to the whole mass, forming the Mohawk group. This would include the Mohawk, Birdseye, and Trenton limestones, and the calciferous sandrock might also be included as the lower member."

The classification, however, that was to become standard for more than a half century, although it introduced some unwarranted changes in the defined use of terms, was proposed five years later.[16] Hall subdivided the New York rocks into Potsdam sandstone, Calciferous sandstone, Chazy limestone, Birdseye limestone, Black-river limestone, Trenton limestone, Utica slate, and Hudson-river group. He had restricted the term "Black-river" to the upper beds of Vanuxem's classification,

[14] Ebenezer Emmons: *Geology of New York. Part II, comprising the survey of the second geological district* (1842) p. 99-118. Albany.

[15] James Hall: *Geology of the Western States*, Am. Jour. Sci., vol. 42 (1842) p. 52.

[16] James Hall: *Paleontology of New York. Volume I, containing descriptions of the organic remains of the lower division of the New York system (equivalent of the Lower Silurian rocks of Europe)* (1847) p. 1-338. Albany.

and included the shales of Conrad's original Trenton in the Utica slate, as Vanuxem had done.

The terms, as Hall had used them, were the foundation of the classification in the most widely used and influential of the American textbooks of the last half of the century,[17] and the redefined usage of "Black River" persisted in textbooks of the present century.[18] Dana subdivided a "Potsdam Period" into the Potsdam and Calciferous epochs. The "Trenton Period" had two epochs, the Chazy and "Trenton, or epoch of the Birdseye, Black River and Trenton limestones."

The Geological Survey of Canada was instituted in 1843. The survey followed,[19] with slight modification, the classification that had been proposed by Hall. In the final report,[20] the classification approached that of Dana in having above the Calciferous group and the Chazy group, a "Trenton group", comprising the "Birdseye and Black River formation, and the Trenton formation." As in the case of New York, there was little refinement in the classification of the sediments in the half century following the first survey, although some areal and faunal descriptions were published.

DEVELOPMENT OF THE STANDARD CLASSIFICATION (1890–1932)

After a lapse of fifty years, interest returned in the last decade of the nineteenth century to the limestones south and southeast of the Adirondacks.[21] Similar studies extended into the vicinity of Lake Champlain.[22] Subsequently, the old "Mohawk limestone" of Conrad, or "base

[17] J. D. Dana: *Manual of geology* (1863) p. 169. Philadelphia.

[18] T. C. Chamberlin and R. D. Salisbury: *Geology. Volume II, Earth history* (1905) p. 310. New York.

A. W. Grabau: *Comprehensive geology. Part II, Historical geology* (1921) p. 260. New York.

[19] W. E. Logan: *Geological survey of Canada: report of progress for the year, 1851-1852* (1852) p. 6. Quebec.

Alexander Murray: *Report in geological survey of Canada: report of progress for the year, 1851-1852* (1852) p. 57-91. Quebec; *Report in geological survey of Canada: report of progress for the year, 1852-1853* (1854) p. 75-152. Quebec.

[20] Geological Survey of Canada: *Report of progress from its commencement to 1863* (1863) p. 138-197. Montreal.

[21] N. H. Darton: *Geology of the Mohawk Valley in Herkimer, Fulton, Montgomery and Saratoga counties*, N. Y. State Geol., 13th Ann. Rept. (1894) p. 407-429.

T. G. White: *Faunas of the upper Ordovician strata at Trenton Falls, Oneida county, New York*, N. Y. Acad. Sci., Tr., vol. 15 (1896) p. 71-96.

C. S. Prosser and E. R. Cumings: *Sections and thickness of the Lower Silurian formations on West Canada Creek and in the Mohawk Valley*, N. Y. State Geol., 15th Ann. Rept. (1897) p. 24-34, 615-659.

T. G. White: *Report on the relations of the Ordovician and Eo-Silurian rocks in portions of Herkimer, Oneida and Lewis counties*, N. Y. State Mus., 51st Ann. Rept. (1899) p. 21-54.

E. R. Cumings: *Lower Silurian system of eastern Montgomery county, New York*, N. Y. State Mus., Bull. 34 (1900) p. 419-488.

C. S. Prosser: *Notes on the stratigraphy of the Mohawk Valley and Saratoga county*, N. Y. State Mus., Bull. 34 (1900) p. 469-482.

P. E. Raymond: *The faunas of the Trenton at the type section and at Newport, New York*, Bull. Am. Paleont., no. 17 (1903) 18 pages.

[22] T. G. White: *Upper Ordovician faunas in Lake Champlain Valley*, Geol. Soc. Am., Bull., vol. 10 (1898) p. 452-462.

P. E. Raymond: *The Crown Point section*, Bull. Am. Paleont., no. 13 (1903) 44 pages.

of the Trenton limestone" of Vanuxem, was designated the Amsterdam limestone.[23] The term "Glens Falls limestone" was applied to the limestones of the Trenton group south and east of the mountains.[24]

While this work was progressing, the classification was altered with the substitution of place names for some of the lithologic designations that had persisted. Clarke and Schuchert revived the name "Mohawk" as the "Mohawkian series" in somewhat the same sense that Hall had used "Mohawk group," but restricted it to include his Birdseye, Black River, and Trenton limestones.[25] The name "Lowville limestone" was substituted for the Birdseye limestone. The Mohawkian series was placed in the "Champlainic System," which was the Champlain group, with the Potsdam sandstone excluded, of the first survey's final reports.

Interest in the stratigraphy of the Mohawkian formations in northwestern New York was practically dormant from the publication of the final report of Emmons in 1842 until the revision of his work was undertaken toward the close of the first decade of this century. Cushing introduced the name "Pamelia limestone" for that part of the original Black River limestone lying below the Lowville.[26] In the report on the Thousand Islands region,[27] the application of the term Black River approached the original definition of Vanuxem, but the Pamelia was considered older than the Mohawkian series and thus excluded from the base of the Black River group. The term "Watertown limestone" replaced the "Seven-foot tier" of the first survey, and the inadvertently used "Black River limestone" of Hall; the underlying cherty beds were segregated as the "Leray limestone member of the Lowville formation."

In Ontario, the description of the areal distribution of the Mohawkian strata from Kingston to Lake Huron[28] was accompanied by the publication of classifications that for the first time differentiated the formations

[23] H. P. Cushing: *Nomenclature of the lower Paleozoic rocks of New York*, Am. Jour. Sci., 4th ser., vol. 31 (1911) p. 141.

[24] Rudolf Ruedemann: *The lower Silurian shales of the Mohawk Valley*, N. Y. State Mus., Bull. 162 (1912) p. 22.

[25] J. M. Clarke and Charles Schuchert: *Nomenclature of the New York series of geologic formations*, Science, n. s., vol. 10 (1899) p. 874-878.

[26] H. P. Cushing: *Lower portion of the Paleozoic section in northwestern New York*, Geol. Soc. Am., Bull., vol. 19 (1908) p. 155-176.

[27] H. P. Cushing, Rudolf Ruedemann, *et al.: Geology of the Thousand Islands region*, N. Y. State Mus., Bull. 145 (1910) 145 pages.

[28] R. W. Ells: *The district around Kingston, Ontario*, Geol. Surv. Canada, Summ. Rept. for 1901, pt. A (1902) p. 172-185.

W. A. Johnston: *The Peterborough sheet*, Geol. Surv. Canada, Summ. Rept. for 1905 (1906) p. 92-94; *Peterborough, Prince Edward and Simcoe sheets*, Geol. Surv. Canada, Summ. Rept. for 1906 (1906) p. 56-58; *Peterborough and Simcoe sheets*, Geol. Surv. Canada, Summ. Rept. for 1907 (1908) p. 56-58; *Simcoe sheet, Ontario*, Geol. Surv. Canada, Summ. Rept. for 1908 (1909) p. 97-102; *Simcoe district, Ontario*, Geol. Surv. Canada, Summ. Rept. for 1909 (1910) p. 158-163; *Simcoe district, Ontario*, Geol. Surv. Canada, Summ. Rept. for 1910 (1911) p. 188-192; *Geology of Lake Simcoe area, Ontario, Brechin and Kirkfield sheets*, Geol. Surv. Canada, Summ. Rept. for 1911 (1912) p. 253-261; *Geology of Lake Simcoe area, Ontario: Beaverton, Sutton and Barrie sheets*, Geol. Surv. Canada, Summ. Rept. for 1912 (1914) p. 294-300.

of the Trenton group. In the later reports on the district, the divisions of the Kirkfield (or Trenton) group were distinguished in ascending order as the "*Dalmanella* beds," "Crinoid beds," "*Prasopora* beds," and "*Hormotoma* and *Rafinesquina deltoidea* beds."

Raymond later applied place names to the divisions. The *Dalmanella* beds were included in the "*Triplecia extans* zone" or Rockland formation, the Crinoid beds became the Hull formation, and the *Prasopora* beds became a restricted "Trenton formation."[29] The overlying beds were subdivided into the "*Rafinesquina deltoidea* zone" and "*Fusispira* and *Hormotoma* zone," and designated the Lower Picton and Upper Picton formations, respectively. These five formations were placed in the Trenton group, and succeeded by the "Utica group," which had zones of "*Ogygites canadensis*" and "*Climacograptus typicalis*," the former being called the Collingwood formation, the latter the restricted "Utica formation," subsequently the Gloucester formation.[30] In his last classification, Raymond placed the Collingwood formation in the Trenton Group, and, the name Picton being preoccupied, it was replaced by Cobourg.[31]

The *Prasopora* beds, or "Trenton formation (restricted)" being only a part of the Trenton group, became the Sherman Fall limestone; and the term Chaumont formation was applied to the undifferentiated post-Lowville members of the Black River group, the Glenburnie shale being one of the members.[32] Recently,[33] the Pamelia limestone has been re-assigned to the Black River group of which it was an original part. Thus, the present standard classification of the Mohawkian series has been developed in northwestern New York and eastern Ontario (Fig. 8).

DIFFERENTIATION OF MOHAWKIAN SHALES (1901–1935)

The differentiation of the shaly formations of Mohawkian age was not successfully investigated until the beginning of the twentieth century. Mather[34] had written that of the rocks in the Hudson River valley, "the lowest in the series is the *Hudson river slate* group, consisting of slates, shales and grits, with interstratified limestones, all of which occur under various modifications." Subsequently, these beds were correlated with the shales of western New York and classified as of late Ordovician age.

[29] P. E. Raymond: *The Trenton group in Ontario and Quebec*, Geol. Surv. Canada, Summ. Rept. for 1912 (1914) p. 342-350.

[30] P. E. Raymond: *Expedition to the Baltic provinces of Russia and Scandinavia; Part I, The correlation of the Ordovician strata of the Baltic basin with those of eastern North America*, Harvard Coll. Mus. Comp. Zool., Bull. 56 (1916) p. 255.

[31] P. E. Raymond: *A contribution to the description of the Trenton group*, Geol. Surv. Canada, Mus. Bull. 31 (1921) p. 1.

[32] G. Marshall Kay: *Stratigraphy of the Decorah formation*, Jour. Geol., vol. 37 (1929) p. 661.

[33] A. E. Wilson: *Notes on the Pamelia Member of the Black River formation of the Ottawa Valley*, Am. Jour. Sci., 5th ser., vol. 24 (1932) p. 135-146.

[34] W. W. Mather: *Fourth annual report of the first geological district of the State of New York*, N. Y. Geol. Surv., 4th Ann. Rept. (1839) p. 212.

Ruedemann,[35] after demonstrating that the correlation was in error, employed "the term Normanskill shales for the clastic facies of a part of the lower Trenton which is characterized by the graptolite fauna at the Normanskill." This shale was later described as synchronous with the Black River and lower Trenton.[36]

The shales along the Mohawk Valley that had comprised Eaton's Graywacke were also found capable of differentiation. For the older black shale, part of the "Utica shale" of preceding authors, Ruedemann[37] proposed the term "Canajoharie shale." "Possibly it contains only lower Trenton, but probably it belongs in large part between the lower and middle Trenton." The "Trenton-Utica passage beds"[38] were named the "Dolgeville shales" by Cushing.[39] Similar shaly limestones along the northern part of Lake Champlain had been referred to as the "Cumberland Head shales."[40] The succeeding "Stony Point black shale" was correlated with the late Trenton,[41] and thought to be equivalent to the upper Canajoharie.

To the interbedded graywackes and shales succeeding the Canajoharie shale in the lower Mohawk Valley, Ruedemann applied the term "Schenectady formation,"[42] with the opinion that "they are at least as old as the upper Trenton, and probably belong mainly between the middle and upper Trenton." The "Snake Hill beds,"[43] similar in fauna and age to the Canajoharie, were believed to have been deposited in a separated, eastern trough, with the older Normanskill shale. Recently, the faunal zones in the shales have been given locality names.[44]

Thus, the studies of the early part of this century showed that the "Hudson River beds" of the eastern part of New York included strata of several ages and had separable faunas. Subsequently, attention has been turned to the stratigraphy and classification of the younger shales in the area southwest and west of the Adirondacks, and in Ontario.

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[35] Rudolf Ruedemann: *Hudson River beds near Albany and their taxonomic equivalents*, N. Y. State Mus., Bull. 42 (1901) p. 487-568. The paper reviews the nomenclature and classification of the beds.

[36] Rudolf Ruedemann: *Graptolites of New York; Part 2, Graptolites of the higher beds*, N. Y. State Mus., Mem. 11 (1908) p. 5.

[37] Rudolf Ruedemann: *The lower Siluric shales of the Mohawk Valley*, N. Y. State Mus., Bull. 162 (1912) p. 28.

[38] H. P. Cushing: *Geology of the vicinity of Little Falls, Herkimer county, New York*, N. Y. State Mus., Bull. 77 (1905) p. 63-64.

[39] H. P. Cushing, *in* W. J. Miller: *Geology of the Remsen quadrangle*, N. Y. State Mus., Bull. 126 (1909) p. 21.

[40] H. P. Cushing: *Geology of the northern Adirondack region*, N. Y. State Mus., Bull. 95 (1905) p. 375.

[41] Rudolf Ruedemann: *Age of the black shales of the Lake Champlain region*, N. Y. State Mus., Bull. 227-228 (1921) p. 108-116.

[42] Rudolf Ruedemann: *The lower Siluric shales of the Mohawk Valley*, N. Y. State Mus., Bull. 162 (1912) p. 38.

[43] *Op. cit.*, p. 58.

[44] Rudolf Ruedemann and G. H. Chadwick: *Ordovician black shales of New York*, Science, vol. 81 (1935) p. 400.

Ruedemann found that the black shales succeeding the Canajoharie shale in the upper Mohawk and Black River valleys were capable of separation.[45] Three divisions were recognized in the Mohawk Valley, of which only the upper extends into the West Canada Creek and Black River valleys.[46] The two lower divisions were considered synchronous with the Cobourg formation, and the upper with the Collingwood and Gloucester formations of Ontario; all were placed in the "Utica group" of the Cincinnatian series. The black shales succeeding the limestone in northwestern New York were considered to be younger than the typical Utica, and equivalent to the Gloucester formation; they were designated the "Deer River shale." [47]

Parks restudied the Collingwood and Gloucester formations [48] and considered the latter to belong in the Upper Ordovician. To the blue shales succeeding the Collingwood at its type section, and believed to be of Gloucester age, he gave the name "Blue Mountain formation."

FORMATIONS OF THE TRENTON GROUP

UNDERLYING BEDS

In the preceding section, the history of the classification of the Mohawkian series has been summarized. The sediments are separable into two groups, the Black River and the Trenton, whose limestone facies are most fully developed in northwestern New York and southeastern Ontario. The classification and sequence of the divisions in this standard section are shown in Figure 8.

The Black River group is composed of three formations. The Pamelia formation is limited in its distribution to the Thousand Islands region and the Ottawa Valley. The beds are overlapped southeastward along the Black River valley, being absent in the valley of West Canada Creek; they similarly thin westward to disappear within or about Hastings County, Ontario. The Lowville limestone is the most persistent of Black River formations, extending throughout the area of Mohawkian outcrop except in local areas southwest and northeast of the Adirondack Mountains. The Chaumont formation crops out in northwestern New York and southern Ontario, but is absent in the Mohawk Valley, and is not typically represented in the Ottawa Valley; along Lake Champlain the formation is well developed at Crown Point, but it is absent in many other sections.

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[45] Rudolf Ruedemann: *The Utica and Lorraine formations of New York*, N. Y. State Mus., Bull. 258 (1925) 175 pages.

[46] G. Marshall Kay: *The Ordovician Trenton group in northwestern New York: stratigraphy of the lower and upper limestone formations*, Am. Jour. Sci., 5th ser., vol. 26 (1933) p. 12-13.

[47] Rudolf Ruedemann: *op. cit.*, p. 52.

[48] W. A. Parks: *Fauna and stratigraphy of the Ordovician black shales and related rocks in southern Ontario*, Royal Soc. Canada, Tr., vol. 22, sec. 4 (1928) p. 60.

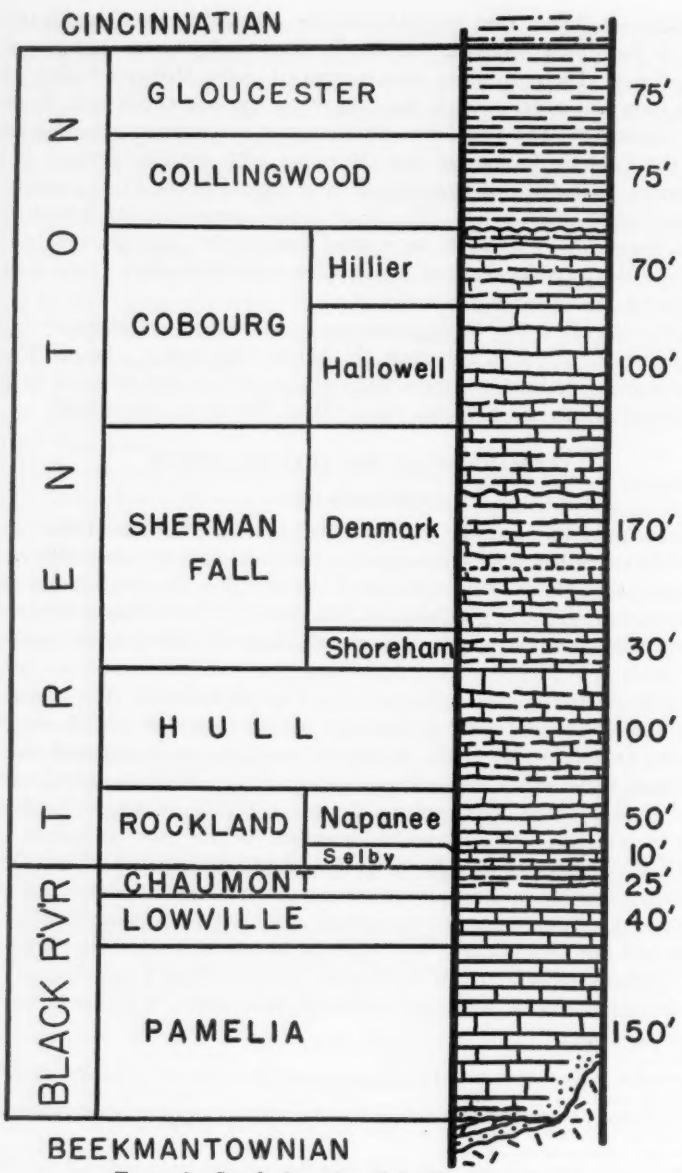

FIGURE 8.—*Standard section of the Trenton group*

The definition, distribution, and characteristic fauna of each of the Trenton formations will be presented in the order of stratigraphic succession, commencing with the oldest, the Rockland.

In the classification of the sediments of the Trenton group, it has seemed less confusing to redefine the limits of certain named units than to introduce new terms. Within some part of its distribution, each formation and member is believed to be lithologically distinct; traced laterally, the differences may become obscure and faunal evidence may be the useful basis of recognition. Lateral changes alter the rank of certain synchronous units from one part of the region to another; the units have been given the rank that seems most useful within each area of outcrop.

FORMATIONS OF ROCKLAND AGE

Rockland limestone.—The Rockland limestone (Rockland, Russell County, Ontario) comprises the "lowest Trenton beds in the Ottawa Valley and central Ontario."[49] In the type section, it has been described as consisting of 40 feet of heavy-bedded limestones, separated from the "Lowville" limestone by 18 feet of "Leray beds of the Black River."[50] These "Leray beds" of the Ottawa district carry a fauna in which *Doleroides ottawanus* Wilson is abundant; a similar fauna directly overlies the Watertown limestone, the top of the Black River group, at Watertown, New York.[51] It is believed that the "Leray beds" at Rockland are post-Watertown, rather than being the pre-Watertown Leray limestone of New York. The Rockland formation in its type section is, therefore, revised to include these "Leray beds"; the close similarity of their fauna to that of the overlying beds has been recognized.[52]

DISTRIBUTION: Westward from the type locality, the Rockland formation extends in rather continuous outcrop to Renfrew County, and it is exposed in large outliers along the Bonnechere River and in the vicinity of Pembroke,[53] and in small areas as far up the river as Mattawa.[54] In localities from Rockland to Pembroke it is underlain in many exposures by from 3 to 5 feet of shaly limestones in which are large masses of *Tetradium* sp. cf. *T. fibratum Safford;* these latter beds are tentatively referred to the upper Black River Chaumont formation and succeed limestones lithologically like the Lowville limestone, bearing *T. cellulosum* (Hall).

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[49] P. E. Raymond: *The Trenton group in Ontario and Quebec,* Geol. Surv. Canada, Summ. Rept. for 1912 (1914) p. 348-349.

[50] A. E. Wilson: *The range of certain lower Ordovician faunas of the Ottawa Valley,* Geol. Surv. Canada, Bull. 33 (1921) p. 26.

[51] Rudolf Ruedemann: *Geology of the Thousand Islands region,* N. Y. State Mus., Bull. 145 (1910) p. 86-90.

[52] A. E. Wilson: *The range of certain lower Ordovician faunas of the Ottawa Valley,* Geol. Surv. Canada, Bull. 33 (1921) p. 26.

[53] R. W. Ells: *Report on the geology and natural resources of the area included in the northwest quarter-sheet, number 122 of the Ontario and Quebec series,* Geol. Surv. Canada, Pub. 977 (1907) p. 24-28, 32-37.

[54] A. E. Barlow: *Geology and natural resources of the Nipissing and Timiskaming map-sheets,* 2d ed., Geol. Surv. Canada, Pub. 962 (1907) p. 120-121.

The Rockland is exposed for 53 feet in the quarry of the Dominion Rock Company, below Eganville, near the fourth chute of the Bonnechere River; *Receptaculites occidentalis* Salter, *Columnaria halli* Nicholson, and *Gonioceras* sp. are found at the top. The first two species are among the many described by Nicholson, Salter, Billings, Foerste, and others, from Pauquette Rapids, on the Ottawa River at the east end of Allumette Island, Quebec, where 9 feet of limestones is exposed. These low Trenton forms have been referred erroneously to the "Leray"[55] and the "Black River."[56] The fauna is quite similar to that of the equivalent Cloche Island Limestone north of Lake Huron, described later.

In southeastern Ontario and northwestern New York, beds characterized by *Doleroides ottawanus* constitute a separable member of the formation designated the "Selby member of the Rockland Formation," from their exposure along Selby Creek, in Lot 22, Conc. III, Richmond Township, Lennox and Addington County, Ontario, a mile north of Napanee station. The overlying beds, characterized in their upper part by *Triplecia cuspidata* (Hall), constitute the type section of the "Napanee member of the Rockland formation." These upper beds are believed to be continuous westward with the Coboconk limestone of central Ontario. The Rockland has a maximum measured section of 64 feet east of Dexter, New York, and is of nearly this thickness on the north shore of Lake Ontario in Lennox and Addington County, Ontario.

Plate 2 portrays the lateral relations of the beds of Rockland age.

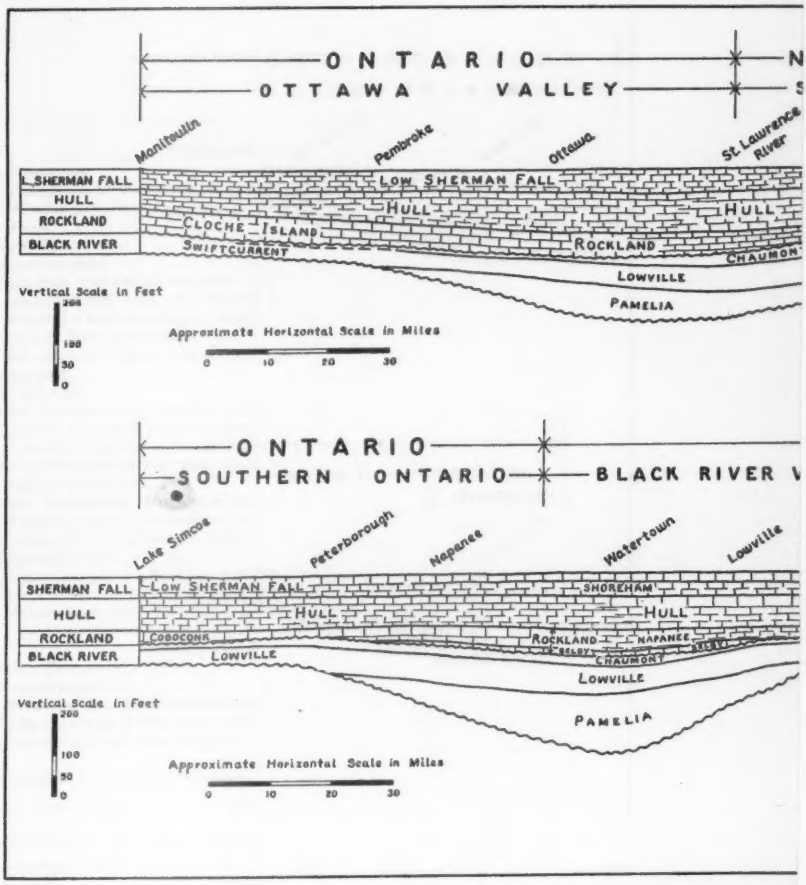
Selby member of the Rockland formation (new).—The Selby member (Selby Creek, Lennox and Addington County, Ontario) is defined as including the limestones characterized by *Doleroides ottawanus* Wilson succeeding the Black River group and underlying the Napanee member of the Rockland formation in southeastern Ontario and northwestern New York. In the type section, only the upper 4 feet of the member is exposed. This consists of dark-gray to black, medium- to fine-textured, petroliferous limestone in thin beds, weathering buff, and having a jointed, splintery fracture. The lower beds of the overlying Napanee member contrast lithologically in having prominent shaly partings, and an abundance of *Dalmanella rogata* (Sardeson) and *Sowerbyella curdsvillensis* (Foerste), species that are uncommon in the Selby. The contact is quite plane.

In an exposure showing the contact of the Selby on the Watertown limestone, a mile east of Dexter, Jefferson County, New York, the Black River and Trenton beds are separated by an undulating bedding plane. In an earlier description of this section,[57] the thin metabentonite that is 3 feet from the base of the Selby member was mistakenly believed to separate the Leray and Watertown members of the Chaumont formation, and to be the same as a persistent clay at that horizon in the Glenburnie shale of Ontario. The type Hounsfield metabentonite is thus of Selby

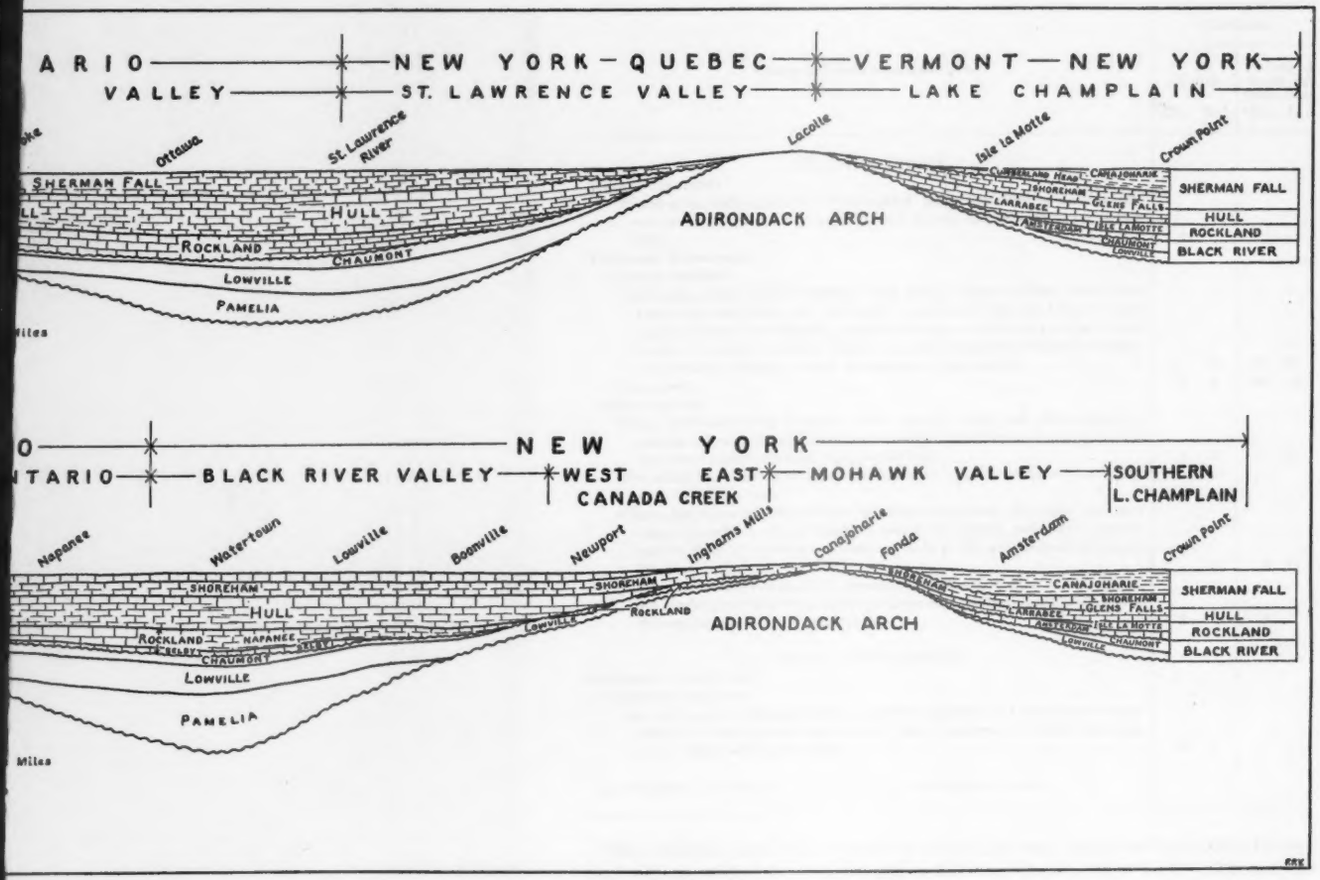
[55] R. S. Bassler: *Bibliographic index of North American Ordovician and Silurian fossils*, U. S. Nat. Mus., Bull. 92 (1915) p. 1452-1458.

[56] A. F. Foerste: *Black River and other cephalopods*, Denison Univ. Bull., Lab. Nat. Hist., vol. 27 (1932) p. 47-136; vol. 28 (1933) p. 1-146.

[57] G. Marshall Kay: *Stratigraphy of the Ordovician Hounsfield metabentonite*, Jour. Geol., vol. 39 (1931) p. 363-364.



RESTORED SECTIONS OF LOWER TREN



RESTORED SECTIONS OF LOWER TRENTON FORMATIONS ACROSS THE ADIRONDACK ARCH

(lower Rockland) age.[58] The revised section of the hill east of Dexter is shown in Table 1.

TABLE 1.—*Section of Rockland formation east of Dexter, New York*

Group and formation description	Thickness	
	Of unit (Ft. In.)	To base of Rockland formation (Ft. In.)
TRENTON GROUP		
HULL FORMATION:		
Bluish-gray, buff-weathering, thin-bedded, shaly limestone containing *Encrinurus cybeleformis* Raymond (f), and other fossils; exposed to top of hill, about	6	
ROCKLAND FORMATION:		
Napanee member:		
Light-gray, thin-bedded limestone with shaly, plane partings, with some coarse-textured beds, one arbitrarily considered the top having ripple marks of 2 foot wave length, trending east; in a bed less than 2 feet below its top, *Triplecia cuspidata* (Hall) (c), and the fossil is frequent through the subjacent 10 feet; to base of exposure along roadside	27 6	63 10
Unexposed	28 6	36 4
Selby member:		
Gray, buff-weathering limestone with crinoid stems and *Dalmanella* sp. passing downward into irregularly bedded, medium-textured limestone with some coarse-textured, fossiliferous beds	4 11	7 10
Hounsfield metabentonite: thin, non-persistent, grayish-white, homogeneous clay, to half an inch.		
Black, fine-textured, bituminous limestone containing *Mesotrypa* sp., and a large faunule, in the northeastern part of the quarry, including *Calymene senaria* Hall, (r), *Doleroides ottawanus* Wilson, (f), and *Dalmanella rogata* (Sardeson), (f)	11	2 11
Black, rather heavy-ledged but laminated limestone, similar to that below, but blacker, and with some shaly partings; containing *Doleroides ottawanus* Wilson; base essentially conformable	2	2
BLACK RIVER GROUP		
CHAUMONT FORMATION:		
Watertown member:		
Very dark-gray to black, medium-textured limestone in two or three heavy ledges; to ledge jutting out in north floor of quarry; contains *Gonioceras anceps* (Hall) and other fossils	5 9	

a—abundant, c—common, f—frequent, u—uncommon, r—rare.

DISTRIBUTION: The Selby member is exposed in many localities in southern Lennox and Addington County, Ontario, and in Jefferson County, New York. Although the lithology is somewhat variable, black, medium- to fine-textured, petroliferous limestone with shaly partings is characteristic. The thickness is about 10 feet. Southeastward, the member is represented at Lowville, Lewis County, by 14′ 8″ of black, rather heavy-bedded, black chert-bearing limestone that is underlain by 13′ 2″ of cherty Chaumont limestone, and overlain by the Napanee member. The top of the

[58] G. Marshall Kay: *Distribution of Ordovician altered volcanic materials and related clays*, Geol. Soc. Am., Bull., vol. 46 (1935) p. 230.

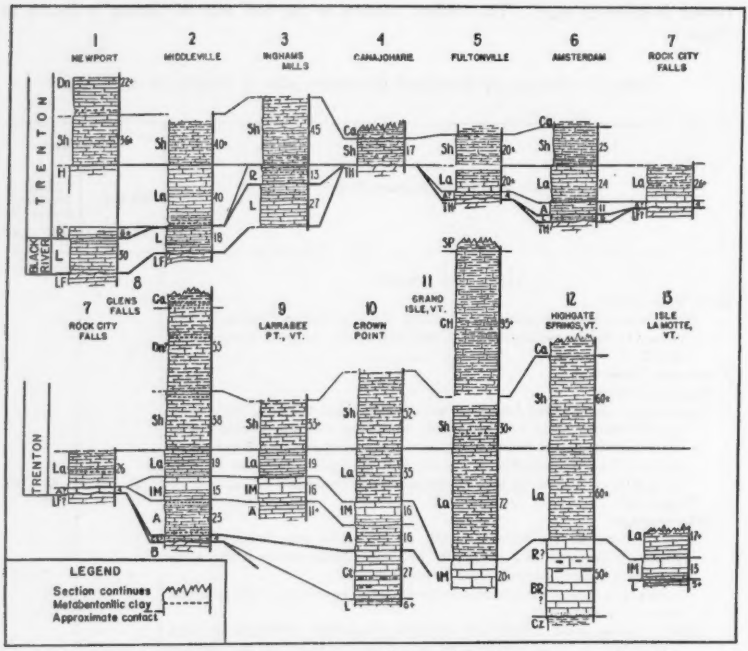


FIGURE 9.—*Stratigraphic sections of lower Mohawkian limestones south and east of the Adirondack Mountains, New York*

The localities from which the sections have been compiled are: 1. Newport, New York: lower beds in quarry northwest of village; higher beds along Rathbone Brook, a mile northwest of Newport. 2. Middleville, New York: quarry along Eatonville Road southwest of Middleville, and along Stony Creek, a mile farther south. 3. Inghams Mills, New York: along East Canada Creek between power house and dam. 4. Canajoharie, New York: along creek south of town; also see Fig. 11. 5. Fultonville, New York: along old Erie Canal and West Shore Railroad, 2 miles west of Fultonville. 6. Amsterdam: composite of section in quarry east of Manny Corners, 3 miles from city, and on Klineville (Swartstown) Creek; *see* Table 3. 7. Rock City Falls, New York: above highway bridge in village, and in quarry just west of stream. 8. Glens Falls, New York: lower beds in Waite Quarry in eastern part of city; higher beds in cement quarry south of river; *see* Table 4. 9. Larrabee Point, Vermont: quarry half a mile south of ferry landing, and adjoining lake shore. 10. Crown Point, New York: along and near shore north of Fort Crown Point. 11. Grand Isle, Vermont: lower beds along lake north of McBrides Bay, South Hero Township; higher beds beyond undetermined interval, between Rockwells Bay and Cumberland Head ferry landing. 12. Highgate Springs, Vermont: from several sections in vicinity of Franklin House. 13. Isle la Motte, Vermont: Hill Quarry and adjacent lake shore.

A—Amsterdam; B—Beekmantown; BR—Black River; Ca—Canajoharie; CH—Cumberland Head; Ct—Chaumont; Cz—Chazyan; Dn—Denmark; H—Hull; IM—Isle la Motte; L—Lowville; La—Larrabee; LF—Little Falls; R—Rockland; Sh—Shoreham; SP—Stony Point; TH—Tribes Hill.

Selby is seen beneath State Street bridge in the village.[59] The member has not been recognized south of East Martinsburg along the Black River valley, and with the

[59] The writer has painted elevations on this and other sections along the Black River valley. The zero in the Lowville Mill Creek section is the top of the Selby member.

exception of two small areas in Herkimer County, equivalent beds are known to be absent along the valleys of West Canada Creek and the Mohawk River (Fig. 9). The quarry at Newport exposes 8 feet of dark limestones that seem to be Selby beds. *Doleroides gibbosus* is abundant in the lower part of the 13′ 4″ of Rockland limestone exposed at Inghams Mills, Herkimer County (Pl. 3, Fig. 1); the species is known to range higher than the Selby member, and in this locality may be of higher Rockland age. In each area these beds have been referred in the past to the "Black River."[60]

Westward in Ontario, the member is absent on the Ameliasburg pre-Cambrian inlier, northwestern Prince Edward County, where the Hull lies on the crystalline rocks, and on the similar Shannonville inlier in Hastings County, where some older beds are irregularly exposed. At Healy Falls, Northumberland County, and in sections farther to the west, younger Rockland beds overlap the upper Black River limestones of the Chaumont formation.

It has been mentioned that the "Leray beds" of the Ottawa district contain a fauna similar to that of the Selby member, and seem to be equivalent. These beds are also found in the Cornwall district,[61] north of the Adirondacks, and in the Westport outlier, northwestern Leeds County, Ontario.[62]

FAUNA: *Doleroides ottawanus* Wilson is characteristic of, and common in, the Selby member throughout its distribution. Associated, but uncommon, are such ubiquitous Trenton species as *Calymene senaria* Hall, *Rafinesquina alternata* (Conrad), *Dalmanella rogata* (Sardeson), and *Sowerbyella curdsvillensis* (Foerste). *Oncoceras collinsi* Foerste is a common cephalopod in the type section, and gastropods are abundant in adjacent beds. The presence of *Columnaria halli* Nicholson, which ranges into beds as young as Sherman Fall in the Mohawk Valley, and *Gonioceras* sp., frequent in the Rockland in several regions, and rarely present in the Hull, has probably been responsible for the confusion of these lowest Trenton beds with the older Black River beds containing species of the same genera. Typical fossils from the beds are shown on Plate 9.

Napanee member of the Rockland formation (new).—The Napanee member (Napanee, Ontario) is defined as including the beds overlying the Selby member and underlying the Hull formation; in southeastern Ontario and northwestern New York, "its top has been considered to be the uppermost bed in which *Triplecia cuspidata* (Hall) occurs",[63] the succeeding Hull formation commonly having *Parastrophina hemiplicata* (Hall) in its lower beds, particularly in New York. In the type section, a mile north of Napanee station, is exposed 34 feet of gray-blue, medium-textured, rather heavy-ledged limestone with shaly partings particularly common in the lower part; the beds are in contact with the Selby member

[60] Percy Raymond: *The faunas of the Trenton at the type section and at Newport, New York*, Bull. Am. Paleont., no. 17 (1903) 18 pages.

H. P. Cushing: *Geology of the vicinity of Little Falls, Herkimer County*, N. Y. State Mus., Bull. 77 (1905) p. 30.

[61] A. E. Wilson: *Ordovician fossils from the region of Cornwall, Ontario*, Royal Soc. Canada, vol. 26, sec. 4 (1932) p. 374.

[62] A. E. Wilson: *Paleontological notes*, Canad. Field-Nat., vol. 46 (1932) p. 133-140.

[63] G. Marshall Kay: *Ordovician Trenton group in northwestern New York: stratigraphy of the lower and upper limestone formations*, Am. Jour. Sci., 5th ser., vol. 26 (1933) p. 4.

at the base, and have *Triplecia cuspidata* at the top, giving a complete section of the member.

DISTRIBUTION: The Napanee crops out in all areas having the Selby member, and in addition overlaps the lower beds along the upper Black River valley. Except in the section at Inghams Mills and the beds at the top of Newport Quarry, it is absent in the West Canada Creek-Mohawk Valley region south of the Adirondacks (Pl. 3); it is represented by about 10 feet of limestones in the infaulted outlier northwest of Wells, in the Lake Pleasant quadrangle, Hamilton County, within the southern Adirondacks. Throughout these districts, the brachiopod *Triplecia cuspidata* persists in its upper part. Westward from Napanee, *Triplecia* has been collected in the top of the 17 feet of very massive, heavy-ledged limestone separating the cherty Chaumont beds from the Hull limestone at Healy Falls, Northumberland County, and south of Halls Bridge (Buckhorn), Peterborough County. These heavy ledges are similar to the Coboconk limestone of central Ontario.

In the type region in Lennox and Addington County, the Napanee crops out over a large part of the higher topography on each side of the Salmon River, north of Napanee as far as Selby Corners, and from Gretna eastward to Bath, in the southern part of the county (Fig. 12). Throughout, the bluish, argillaceous Hull has been stripped from the surface of the Napanee, which is thus a terrace and scarp-forming member. In New York, the formation, being much more shaly, and having few of the heavy ledges of the type area, is relatively non-resistant, and is poorly exposed.

FAUNA: *Triplecia cuspidata* (Hall) is the guide fossil of the upper Napanee, and has not been found at other horizons in the Trenton. *Phragmolites compressus* Conrad is distinctive and most characteristic of the member, although it is also in the overlying Hull, and *Bathyurus spiniger* (Hall) is a characteristic trilobite. Species of *Columnaria, Actinoceras,* and *Stromatocerium,* suggestive of the Black River, are frequently found, together with forms such as *Maclurites logani* Salter, *Receptaculites occidentalis* Salter, and *Hesperorthis tricenaria* (Conrad) that are in greater profusion in the northern equivalents of the Rockland; the latter two are also found in the Hull. Most common of the species in the Napanee are species of the ubiquitous Trenton brachiopod genera *Dalmanella, Sowerbyella,* and *Rafinesquina.* Some of the fossils are illustrated on Plate 9.

Coboconk limestone.—The Coboconk limestone (Coboconk, Victoria County, Ontario) was described by Johnston,[64] who considered the beds the correlatives of the Leray member of the Black River group of New York. In the lime quarries south of the village of Coboconk, the type section exhibits 21 feet of gray, tan-weathering limestone, medium- to coarse-textured, heavy-bedded in the upper part but thin-bedded below. It contains *Hesperorthis tricenaria* (Conrad), *Maclurites logani* (Salter), *Columnaria halli* Nicholson, and *Stromatocerium rugosum* Hall. Underlying it is 11 feet of dark-colored upper Black River, Chaumont limestone, with abundant *Tetradium racemosum* Raymond in the upper 6 inches. The typical dove-gray Lowville limestone is subjacent.

Similar limestones in massive, tough, resistant ledges, weathering to rough, harsh surfaces, extend from west of Coldwater, Simcoe County,

[64] W. A. Johnston: *Simcoe district, Ontario,* Geol. Surv. Canada, Summ. Rept. for 1910 (1911) p. 189.

FIGURE 1. INGHAMS MILLS
Shoreham limestone (above), separated by 13 feet of Rockland limestone from Lowville limestone (below).

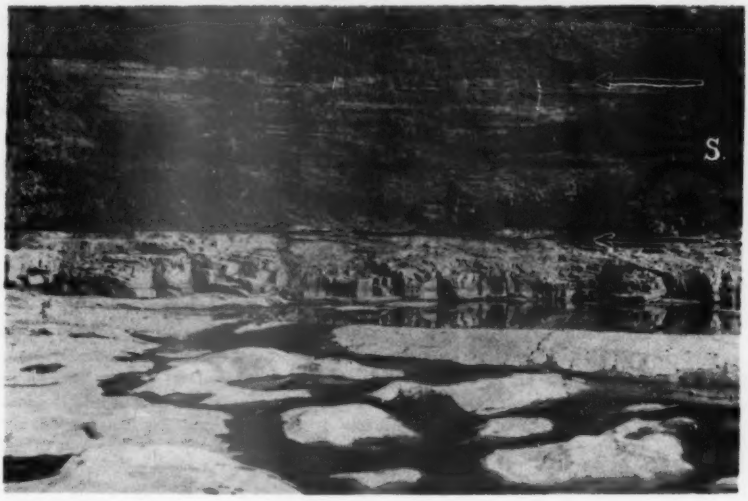


FIGURE 2. CANAJOHARIE CREEK
Canajoharie shale (above), separated by 17 feet of Shoreham limestone from lowest Ordovician Tribes Hill dolomite (below).

near Georgian Bay, to Northumberland County, and are quite like the typical Napanee member of the Rockland formation. Fossils are frequently silicified, and locally gray chert is abundant in beds and veins, the latter reaching a width of several feet south of Dalrymple, Victoria County.

The Coboconk is succeeded by the *"Dalmanella* beds" of Johnston and Raymond, which were classified by Raymond as Rockland. However, in Northumberland and Peterborough counties, limestones lithologically similar to the Coboconk contain *Triplecia cuspidata* in the upper part, and overlie upper Black River, Chaumont limestones. The Coboconk formation contains *Maclurites logani, Receptaculites occidentalis, Hesperorthis tricenaria,* and *Calopoecia huronensis*—forms characteristic elsewhere of the Rockland. The *"Dalmanella* beds", originally called Rockland in this district, are thought to be lower Hull. This interpretation is based on the belief that the beds underlying them are continuous with the upper Rockland, although *Triplecia* has not been found west of Peterborough County. Moreover, the combined thickness of the *"Dalmanella"* and "Crinoid" beds of Central Ontario is similar to that of the known Hull a few miles farther east.

Cloche Island limestone.—The Cloche Island limestone [56] (Great Cloche Island, Manitoulin District, Ontario) has its type section in the bluff west of Swift Current, at the eastern end of the island. The beds have been mistakenly separated into two divisions called the "Leray member of the Lowville" and "Black River limestones." [66] The formation consists of about 55 feet of light-gray, rather heavy-bedded limestone, with argillaceous beds in the lower part; nearly the whole is exposed in the type section, which shows the contact with the underlying Black River beds (Table 2).

The railroad cuts south of the quarries show that the limestone in the lower part of the section has been irregularly dolomitized; thus, a single ledge of *Tetradium*-filled, white, sublithographic limestone can be traced directly into a similar thickness of tan, coarse-textured dolomite. Half a mile to the south, the limestones incline against a projecting knob of pre-Cambrian quartzite—an inlier. The top exposures in the section extend upward to the undulating surface of the stripped top of the Cloche Island formation, which covers most of the southern part of the island. The beds dip beneath the Hull limestone at the narrow Goat Island channel, not more than 10 feet of beds being unexposed beneath the Hull on Goat Island: the covered interval is presumably underlain by shaly Hull.

DISTRIBUTION: The Cloche Island formation extends over much of southern Cloche

[65] A. F. Foerste: *Ordovician section in the Manitoulin area in Lake Huron,* Ohio Nat., vol. 13 (1912) p. 43.

[66] A. F. Foerste: *The Mohawkian (Middle Ordovician) strata northeast of Manitoulin Island,* Geol. Surv. Canada, Guidebook 5 (1913) p. 85-87.

TABLE 2.—*Type section of Cloche Island limestone west of Swift Current, Manitoulin*

Group and formation description	Thickness: Of unit (Ft. In.)	Thickness: To base of Cloche Island formation (Ft. In.)
TRENTON GROUP		
CLOCHE ISLAND FORMATION (Rockland age):		
Gray, buff-weathering, medium-textured, impure, heavy-ledged limestone, containing particularly in upper beds: *Gonioceras* sp. cf. *G. groelandicum* Troedsson, (c); *Maclurites logani* (Salter), (c); *Receptaculites occidentalis* Salter, (c); *Streptelasma profundum* Hall, (a); *Columnaria halli* Nicholson, (f); and a large associated faunule. To top of exposure	37 6	51
Blue-gray, silty limestone and beds of similar thickness of gray and buff siltstone and shale; 11 inches of laminated siltstone at base; *Hesperorthis tricenaria* (Conrad), (c). Exposed in north quarry along Algoma Eastern (C. P.) Ry	13 6	13 6

BLACK RIVER GROUP	Thickness: Of unit (Ft. In.)	Thickness: To base of section (Ft. In.)
SWIFT CURRENT FORMATION (Probably of Chaumont age):		
Gray, buff-weathering, massive, arenaceous, somewhat magnesian limestone with siliceous, ferruginous, "ropy" ridges on upper surface, containing *Streptelasma* sp., and having rolled pebbles of *Tetradium* sp. cf. *T. fibratum* (Safford) and *Columnaria* sp. in base	11	18 7
(Probably of Lowville age):		
Gray, silty, and arenaceous shale; ostracods	7	17 8
White-weathering, greenish-gray, sugary, arenaceous limestone in single ledge	10	17 1
Greenish-gray, platy, calcareous shale, with well-developed sun-cracks	2 1	16 3
White, fine-textured limestone in three laminated ledges with shaly partings; *Tetradium* sp., *Bathyurus extans* (Hall), and many ostracods; appearance similar to Lowville south of Georgian Bay	1 5	14 2
Shale and white limestone to bottom of north quarry	2 9	12 9
Buff dolomite, poorly exposed in upper part, but forming broad anticline in McGregor Bay; containing *Actinoceras* sp. and *Stromatocerium* sp. About	10	10
Reddish-maroon, buff-blotched, silty dolomite, containing obscure, branching bryozoa or "fucoids," exposed at level of lake.		

Island, and must crop out westward along the strike on islands as far west as Clapperton Island. The North Channel of Lake Huron conceals most of the outcrop westward to St. Joseph Island, Algoma District, where there is an exposure along the northwest shore of Recollet Point, south of McMenomy Bay in eastern Hilton Township. Blocks of the limestone were dredged in deepening the channel of the St. Mary's River south of Sailor's Encampment, Ontario, and at the south end of Rains (Little Neebish) Island, Michigan, and in the dredging of the north end of the channel on the west side of Neebish Island, Michigan. The 30 feet of limestones about 10 feet above river level below Bony Falls, 20 miles above the mouth of the Escanaba River, Delta County, Michigan, seems to represent the westward con-

tinuation of the Cloche Island, although there are obvious differences in faunal content.

FAUNA: The extensively exposed upper beds of the formation on Cloche Island commonly contain *Receptaculites occidentalis* Salter, *Maclurites logani* Salter, *Gonioceras* sp. aff. *G. groelandicum* Troedsson, *Actinoceras bigsbyi* (Bronn), *Columnaria halli* Nicholson, *Calopoecia huronensis* Billings, *Streptelasma profundum* Hall, *Camerella panderi* Billings, *Dinorthis sweeneyi* Winchell and Schuchert, and *Hesperorthis tricenaria* (Conrad); the additional fauna is large (Pl. 9). On St. Joseph Island, beds containing such forms as *Gonioceras, Receptaculites,* and *Columnaria* have intercalations containing *Dalmanella rogata* (Sardeson) and *Sowerbyella curdsvillensis* (Foerste). Although most of the cephalopods described from St. Joseph Island have come from older, Black River beds, a few are from the Cloche Island.

The Cloche Island formation is directly overlain by the Hull limestone on Goat Island, south of Cloche Island, and typical Hull faunules have been collected in association with the Cloche Island forms in material from the excavations in Neebish channel, Michigan. The most common species of the formation are known in the Rockland of the Ottawa Valley and of central and southern Ontario.

Amsterdam limestone.—The Amsterdam limestone (Amsterdam, Montgomery County, New York) was named by Cushing,[67] but it has not been satisfactorily defined. In many sections along the Mohawk Valley in the region below Amsterdam, 10 feet of gray-black, rough-fracturing, heavy-ledged limestone lies between a few feet of Lowville limestone and beds of Hull age (Fig. 9). A typical section is that in the quarry half a mile east of Manny Corners, three miles east northeast of Amsterdam (Table 3).

The Amsterdam is absent at Rock City Falls, Saratoga County, but is seen at Glens Falls. In the section in the Waite quarry, below the 16 feet of Isle la Motte limestone, there is 27 feet of beds, most of which belongs in the Amsterdam; there are metabentonites at 5′ and 24′ in the sequence, the lower being 4 inches thick; the lowest 3′ 8″ of limestones are tentatively classified as Chaumont. The most significant section, however, is that at Crown Point, where 16 feet of Amsterdam beds overlies 27 feet of Chaumont limestone, and underlies 16 feet of Isle la Motte. Thus, the Amsterdam limestone is younger than limestones classified as Chaumont, and older than the *Triplecia cuspidata*-bearing upper Rockland.

Referring to Raymond's section,[68] bed 18 is Lowville; beds 19 to 23 (27′ 2″ in the writer's section, cf. 25′ 8″ in Raymond's) are Chaumont. The writer would classify beds 24, 25 and the lower 4′ 1″ of bed 26, which has its base at the floor west of the deeper part of the old marble quarry, as Amsterdam, the top being an irregularly undulating and pitted bedding plane succeeded by coquinal gray limestone, the base of the Isle la Motte; the thickness is 16′ 2″ cf. 18′ 5″. The succeeding part of bed 26 plus beds 27 and 28 (15′ 9″ cf. 19′ 6″) comprise the exposed Isle la Motte, which is followed by a 3′ 4″ (cf. 4′) interval that is probably in the basal Hull (Glens Falls).

FAUNA AND CLASSIFICATION: Most of the fossils in the Amsterdam seem to be ubiquitous species of such genera as *Columnaria, Streptelasma, Rhynchotrema,*

[67] H. P. Cushing: *Nomenclature of the lower Paleozoic rocks of New York,* Am. Jour. Sci., 4th ser., vol. 31 (1911) p. 141.

[68] P. E. Raymond: *The Crown Point section,* Bull. Am. Paleont., no. 13 (1903) p. 21-24.

TABLE 3.—*Section in quarry east of Manny Corners, New York*

Group and formation description	Thickness	
	Of bed (Ft. In.)	To base of formation (Ft. In.)
MOHAWKIAN SERIES		
TRENTON GROUP		
GLENS FALLS FORMATION:		
Shoreham member (lowest Sherman Fall):		
Dark-gray, argillaceous limestone with gray, buff-weathering, shale partings; contains *Cryptolithus tesselatus* Green. These beds 25 feet thick at Klineville (Swartstown), to the south; exposed	5	30
Larrabee member (Hull):		
Gray, coarsely crystalline, heavy-ledged limestone; exposed along the roadside	5	25
Poor exposure	16	20
Dark-gray, buff-weathering, thin-bedded, impure limestone, locally fine-textured and white weathering, containing *Bathyurus ingalli* Raymond, *Encrinurus cybeleformis* Raymond, an abundance of *Strophomena filitexta* (Hall), and many other species; base adhering to underlying bed on pitted surface	4	4
AMSTERDAM FORMATION (probably Rockland):		
Dark-gray, gray-weathering, medium-textured, tough, hackly fracturing limestone with somewhat stylolithic, black, wavy bedding planes; upper bed finer-textured, lighter-weathering; lower bed a conglomerate having Lowville pebbles in gray, calcareous matrix. *Streptelasma* sp., *Strophomena* sp., *Zygospira* sp., and *Columnaria halli* Nicholson, frequent. 7′ 8″ at Swartstown Creek	11 6	11 6
BLACK RIVER GROUP		
LOWVILLE FORMATION:		
Gray, light-gray-weathering, medium- to fine-textured limestone in rather heavy ledges, with some sublithographic limestone; *Phytopsis*, frequent. On Swarztown Creek, these beds are 5′ 7″ thick, and contain *Tetradium celullosum* (Hall), and flat pebble conglomerates [complete]	5 3	5 3
(Distinct unconformity)		
BEEKMANTOWNIAN SERIES		
TRIBES HILL FORMATION:		
Gray, buff-weathering, sugary dolomite, with magnesian shale in the top; forming floor of the quarry		

Zygospira, and *Strophomena* that do not at present permit its exact designation. Inasmuch as only the upper Rockland is above it at Crown Point, whereas the Chaumont beds in that section are comparable in thickness to the type upper Black River, the formation is tentatively classified as lower Rockland.

Isle la Motte limestone.—The Isle la Motte limestone (Isle la Motte, Vermont, in northern Lake Champlain) was named by Emmons,[69] who believed it to be a part of the Black River group, and equivalent to the "Seven foot tier" or Watertown limestone of northwestern New York. The type section in the Hill quarry, on the east side of the island, has 10½ feet of black, gray-weathering, medium-textured, heavy-ledged limestone; *Maclurites logani* (Salter) is abundant in the upper part.

[69] Ebenezer Emmons: *Geology of New York: Part II, comprising the survey of the third geological district* (1842) p. 110. Albany.

The quarry was long a source of commercial marble. The Lowville limestone, below, has *Phytopsis* in abundance in its upper part. The base of the Isle la Motte is probably represented by 2 feet of underlying *Columnaria*-bearing, blue-black limestone, giving it a thickness of 12½ feet. The Isle la Motte is overlain by thinner-bedded limestones of Hull age.

The formation is represented in many sections from this locality southward to Glens Falls, New York, retaining the heavy-ledged lithology of the type section. The maximum thickness measured is 16 feet at Crown Point, New York, where the beds are overlain by the Hull, and underlain by 16 feet of Amsterdam limestone, probably of lower Rockland age.

FAUNA: The Isle la Motte limestone, in addition to having *Maclurites logani* common in its upper part, commonly contains *Receptaculites occidentalis* Salter, *Columnaria halli* Nicholson, *Stromatocerium rugosum* Hall, and *Hesperorthis tricenaria* (Conrad), all of which are found with *Triplecia cuspidata* (Hall) [70] in the section at Crown Point. Thus, the fauna is one more similar to that in the Ontario Rockland than to that of the equivalent beds west of the Adirondacks. The fact that the beds are consistently overlain by the lower Glens Falls Larrabee limestone, with its Hull fauna, supports the Rockland designation.

FORMATIONS OF HULL AGE

Hull limestone.—The Hull limestone (Hull, Quebec) includes the "Strata which at Ottawa, Belleville, and in Central Ontario carry the well-known crinoid fauna." [71] In southeastern Ontario and New York, the formation extends from the top of the *Triplecia cuspidata*-bearing Napanee member of the Rockland formation to the base of the Sherman Fall limestone, in which *Prasopora orientalis* Ulrich is abundant. *Parastrophina hemiplicata* (Hall) normally is abundant in the basal Hull in New York, is rare in the top Rockland, and recurs at higher horizons; thus, its presence aids in distinguishing Hull from Rockland.

In these areas and in the Ottawa Valley, the formation is composed of limestones with shaly partings. In northwestern New York, limestone beds include gray, thick beds of coarse texture that have large pararipple-marks with a preponderant northwest-southeast trend. The upper part of the formation, being more resistant than the succeeding shaly Sherman Fall, forms terraces and falls, such as Kings Falls on Deer River, High Falls on Stony Creek at Denmark, and the falls on Sugar River near Denley. The thickness of the Hull ranges from 85 to 110 feet. In southern Ontario, brownish to gray, sugary, fossiliferous limestones in the lower Hull are overlain by similar ledges having intercalated, bluish-gray clay partings and interbeds; the former are the "*Dalmanella* beds" of Central Ontario. The thickness is comparable to that in New York.

[70] P. E. Raymond: *op. cit.*, p. 24, 38, pl. 19, fig. 4, as *T. extans* (Hall).

[71] P. E. Raymond: *Trenton group in Ontario and Quebec*, Geol. Surv. Canada, Summ. Rept. for 1912 (1914) p. 348-349.

DISTRIBUTION: The more typical, crinoid-bearing, bluish, shaly Hull limestone extends from St. Mary's River in northeastern Michigan to the Ottawa Valley and southeastern Ontario. The thickness is only about 40 feet on Goat Island, Manitoulin District, but although the thickness in central Ontario has been reported as only 35 feet,[72] this is the thickness of the "Crinoid beds" alone, and the writer has presented evidence suggesting that the 40 feet of underlying "*Dalmanella* beds" should also be included in the Hull, inasmuch as the subjacent Coboconk limestone is believed to be upper Rockland in its eastern extension.

In its original usage, the term Kirkfield limestone[73] (Kirkfield, Victoria County, Ontario) was synonymous with the Hull formation, but the term Kirkfield later was applied as a provincial name for the Trenton group of central Ontario.[74]

The formation extends in a belt south of that of the Rockland formation from the vicinity of Midland, through Lake Simcoe, Kirkfield, Lakefield, and Belleville to Deseronto; it passes beneath Picton Bay along the Picton monocline, and reappears across the southern peninsula of Lennox and Addington County, reaching the shore at Sandhurst, and underlying the northeastern half of Amherst Island. It enters New York at Sacket Harbor, forms a narrowed belt south and west of the Black River as far as Boonville, and then thins rapidly toward the Mohawk Valley, where it constitutes the Larrabee member, the lower part of the Glens Falls formation.

Plate 2 portrays the lateral relations of beds of Hull age.

FAUNA: The Hull formation has a large total fauna, many species of which are common only to local bioherms. Among the distinctive and persistent forms are the trilobites *Encrinurus cybeleformis* Raymond, *Hemiarges paulianus* (Clarke), and *Bathyurus ingalli* Raymond (Pl. 9); none of these is known from horizons not in the Hull. In northwestern New York and southern Ontario, the basal Hull is the lowest member in which *Parastrophina hemiplicata* (Hall) is abundant; it is found also in younger formations. *Strophomena filitexta* (Hall) is common, and, in contrast to the Rockland, specimens of *Rafinesquina* are few. *Hesperorthis tricenaria* (Conrad) and *Receptaculites occidentalis* Salter are not found above the Hull and the genus *Platystrophia* is first represented by uncommon species in the formation. Several classes of organisms are locally abundant. More than three score species of crinoids, cystids and starfishes have been taken from the formation at Kirkfield and Ottawa, Ontario.[75] Thin zones and ledges replete with species of gastropods and cephalopods are found in many sections. An ostracod faunule of 25 species has come from a single bed north of Campbellford, Ontario.[76] The fauna of the formation is prolific and characteristic, permitting its differentiation from other Trenton formations.

Larrabee member of the Glens Falls formation (new).—The Larrabee member (Larrabee Point, Addison County, Vermont) constitutes the lower portion of the Glens Falls formation [77] (Glens Falls, New York) that is of Hull age, the upper Glens Falls being lowest Sherman Fall; thus, it is the lower, Larrabee, member of the Glens Falls formation. In the type

[72] *Op. cit.*, p. 346.

[73] W. A. Johnston: *Simcoe district, Ontario*, Geol. Surv. Canada, Summ. Rept. for 1909 (1910) p. 158.

[74] W. A. Johnston: *Simcoe district, Ontario*, Geol. Surv. Canada, Summ. Rept. for 1910 (1911) p. 189.

[75] Frank Springer: *On a Trenton echinoderm fauna at Kirkfield, Ontario*, Geol. Surv. Canada, Mem. 15 (1911) 68 pages.

[76] G. Marshall Kay: *Mohawkian Ostracoda: species common to Trenton faunules from the Hull and Decorah formations*, Jour. Paleont., vol. 8 (1934) p. 328-343.

[77] Rudolf Ruedemann: *The lower Siluric shales of the Mohawk Valley*, N. Y. State Mus., Bull. 162 (1912) p. 28.

section in the quarry a quarter of a mile south of Larrabee Point, the member is composed of about 20 feet of bedded, relatively pure limestones above 15′ 6″ of heavier-ledged Isle la Motte limestone that overlies the *Columnaria*-bearing top of the Amsterdam limestone in the eastern part of the quarry. The base of the *Cryptolithus*-bearing upper Glens Falls, the Shoreham member of lowest Sherman Fall age, is just above the principal quarry face.

The Larrabee member varies considerably in lithology and thickness (Fig. 9). In the lower Mohawk Valley, the member, composed of thin-bedded limestones with coarse-textured ledges in the upper part, has a thickness of 15 to 25 feet between Pattersonville and Fultonville; it lies on Lowville toward the west, and the Amsterdam intervenes toward the east. Beds of Hull age are lacking from above Fultonville, at Sprakers and Canajoharie (Pl. 3), to the vicinity of Manheim, in Herkimer County. North of the Mohawk, there are thin Hull beds in the Wells infaulted outlier, Hamilton County; and only 4 feet of Amsterdam (?) separates the Larrabee from the Beekmantown at Rock City Falls, Saratoga County.

Along Lake Champlain, the limestones are thin-bedded and somewhat shaly, similar to the equivalent beds of western New York; the thickness increases from 16 to 20 feet south of the lake, to 35 feet at Crown Point, and to a maximum of 72 feet north of McBride Bay, South Hero Township, Grand Island County, Vermont. About 60 feet of similar limestones is in the Highgate Springs series, in the overthrust belt just south of the Quebec line east of Missisquoi Bay. The stratigraphic position above the Rockland Isle la Motte limestone and below the lowest Sherman Fall Shoreham limestone supports the classification of the Larrabee member in the Hull.

FORMATIONS OF SHERMAN FALL AGE

Sherman Fall limestone.—The Sherman Fall limestone (Sherman Fall, Trenton Falls gorge, New York) comprises the "*Prasopora* beds" or "Trenton (restricted)" of Raymond, Johnston, and others,[78] overlies the Hull formation and underlies the Cobourg limestone in northwestern New York and Ontario. The base of the formation is distinguished by the abundance of specimens of *Prasopora orientalis* Ulrich, a bryozoan that rarely, if ever, is found in other formations. The differentiation of the Sherman Fall from the lower Cobourg is arbitrary and difficult, for, although the lower Sherman Fall and higher Lower Cobourg have persistent guide fossils, none that are both distinctive and abundant have been discerned in the intermediate beds. *Pasceolus globosus* Billings ("*Ischadites* sp.") is locally abundant in the base of the Cobourg in northwestern New York and in Prince Edward County, Ontario, and has been considered to mark the top of the Sherman Fall.

The type section at Sherman Fall lacks exposure of about 30 feet of the base of the formation, but the total thickness in the vicinity is about 200 feet, as in other sections northwestward as far as Georgian Bay.

The formation is generally more shaly than the adjacent formations,

[78] G. Marshall Kay: *Stratigraphy of the Decorah formation*, Jour. Geol., vol. 37 (1929) p. 664.

but the lithology is variable. At Trenton Falls, dark, brownish-weathering, calcareous shales have dark-gray, dense limestone interbeds; coarse-textured beds are infrequent. In the lower Black River Valley and in southern Ontario, intercalated coarse limestones have anastomosing para-ripples. The contrast between the Sherman Fall and the Hull in central Ontario is shown in quarries at Lakefield and Kirkfield; the limestones in the former locality have thick intercalated beds of calcareous claystone, whereas shale partings are much thinner in the Hull beds at Kirkfield. Metabentonites, at several horizons in the lower half of the Sherman Fall, are thin, seem non-persistent, and have not been successfully correlated.

DISTRIBUTION: The entire Sherman Fall limestone crops out in the upper part of the valley of West Canada Creek, Herkimer and Oneida counties; it reappears west of the Black River and forms a belt of terraces and bluffs intermediate in elevation northwest to Watertown; thence it trends westward to the east side of Henderson Bay, Lake Ontario. It forms the southwestern half of Amherst Island, the north shore of Prince Edward County, and part of the intervening peninsula of Lennox and Addington County. The belt of outcrop through Trenton, Peterborough, and Lake Simcoe to the east side of Nottawasaga Bay of Lake Huron is for the most part obscured by glacial cover. In Ontario, the formation is composed of lighter-colored, more evenly bedded limestones than those in New York.

Southeast of Gravesville below Trenton Falls, the limestones of Sherman Fall age become thinner, their upper part being replaced by black shale through the Dolgeville interbedded facies. At Inghams Mills, coarse-textured limestones of lowest Sherman Fall age are exposed for 45 feet; they contain, in the lowest part, abundant, flat, rounded pebbles up to 10 inches long, derived from the underlying formations, the thin and isolated Rockland, the Lowville and Beekmantownian; no crystalline pebbles were seen. A few miles to the east, at Canajoharie and Sprakers, about 16 feet of similar limestones has separating dark shaly beds, and lies with distinct disconformity on the Beekmantownian and similarly below the Canajoharie black shale of later Sherman Fall age (Pl. 3, Fig. 2). Rounded and angular blocks of Beekmantownian dolomite up to 2 feet in diameter are common at Sprakers; smaller, flat pebbles abound in lower beds.

The *Cryptolithus*-bearing lowest Sherman Fall limestones persist eastward as the Shoreham member of the Glens Falls formation, and also form the lowest part of the typical Sherman Fall limestone, being overlain in western New York by the Denmark member, which constitutes the remainder of the formation. The latter is represented south and east of the Adirondacks by a number of shale formations, of which the Canajoharie formation is typical.

Plate 4 portrays the lateral continuity of beds of Sherman Fall age. Their correlation is shown in Figure 10.

Shoreham member of the Sherman Fall formation (new).—The Shoreham member (Shoreham Township, Addison County, Vermont) constitutes the zone of *Cryptolithus tesselatus* Green, the limestones of lowest Sherman Fall age. In its type region in the lower Mohawk, upper Hudson and southern Lake Champlain areas, the beds comprise the upper

Glens Falls limestone, overlie the lower Glens Falls Larrabee member of Hull age, and underlie the Canajoharie shale of later Sherman Fall age (Fig. 9). The beds consistently contain *Cryptolithus tesselatus,* which is limited to the member, and *Prasopora orientalis* Ulrich and *Trematis terminalis* (Emmons) (Pl. 10). This zone has been found to persist in

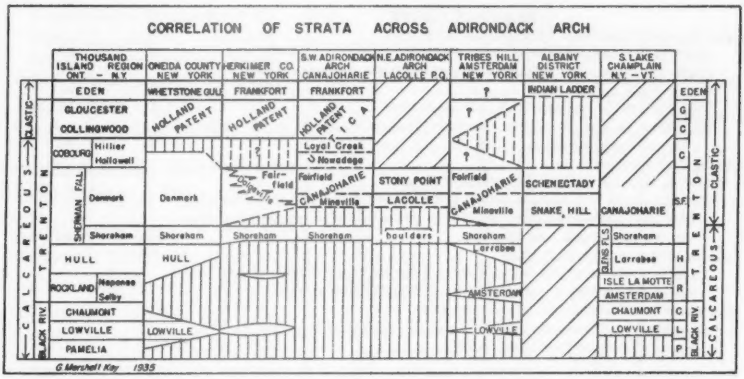


FIGURE 10.—*Correlation of Mohawkian formations adjacent to the Adirondack Arch* Showing the contrasting lithologies on the two sides of the Adirondack Arch and the unconformities along the axis.

the Sherman Fall northwestward to Lennox and Addington County, Ontario, in the equivalent beds of northern Lake Champlain, and northeastward to the city of Quebec.

In the type section, above the quarry of Larrabee Point, Vermont, the lower 36 feet of the member is exposed, a species of *Parastrophina* being abundant 6 feet from the base. The section is much better shown in the quarry of the Glens Falls Portland Cement Company, east of South Glens Falls, New York (Table 4).

The top of the Shoreham member has been arbitrarily drawn, and the higher beds of limestone can conveniently be considered as belonging to the member.

Along the Mohawk Valley, the Shoreham member is composed of 15 (at Morphy Creek) to 25 feet (at Klineville) of dark-gray, calcareous claystones and shales that contrast markedly with the subjacent, heavy-ledged Larrabee member, and are succeeded abruptly by the Canajoharie shale (Fig. 9). The beds persist westward, with a thickness of 20 feet, to west of Fultonville, thinning to 16 feet of coarse-textured limestones at Sprakers and Canajoharie (Fig. 11). There are few complete sections along Lake Champlain, but the member has an exposed thickness of 30 feet north of McBrides Bay, South Hero Township, Grand Isle County, Vermont, with a meta-

TABLE 4.—*Section in cement quarry east of South Glens Falls, New York*

Group and formation description	Thickness	
	Of beds (Ft. In.)	To base of beds of Sherman Fall age (Ft. In.)
TRENTON GROUP		
CANAJOHARIE FORMATION (of Sherman Fall age):		
Black, laminated and jointed shale; exposed	50	147
Black shale with few calcareous interbeds, three prominent black clayey partings in upper 4 feet	24	97
Yellowish, flaky, schistose clay, metabentonite	5	73 5
Dark-gray, calcareous claystone and argillaceous limestone; lowest beds in east end of upper quarry	35	73
GLENS FALLS FORMATION:		
Shoreham member (of lowest Sherman Fall age):		
Gray limestone with shaly interbeds and partings; limestones at 25 feet filled with *Cryptolithus*, which is found with *Prasopora* at other horizons; thin clay metabentonite near the top	38	38
Larrabee member (of Hull age):		
Dark-gray, coarse-textured limestone and thinner-bedded, medium-textured limestone with shaly partings; in north wall of lower quarry	18 10	
ISLE LA MOTTE FORMATION (Rockland age):		
Gray-blue, medium-textured, heavy-ledged limestone, the "marble beds," exposed in lower quarry for about	15	

bentonite 11 feet from the base. The overlying beds are the Cumberland Head shaly limestone and Stony Point shale, both of later Sherman Fall age. In the overthrust Highgate Springs series in extreme northern Vermont, the section is more similar to that of southern Lake Champlain, *Cryptolithus* being common in the lower part of the 60 feet of shaly Sherman Fall limestones that overlie the Hull and pass upward into the black shales. The same zone in the St. Lawrence region extends as far as Montmorency Falls, where it lies on the granite.[79]

In western New York, the *Cryptolithus* zone has been recognized in many exposures of the lower Sherman Fall, and extends upward through from 30 to 40 feet of the beds. Its northwesternmost observed exposure is in southern Lennox and Addington County, Ontario, just east of Sandhurst. Farther westward, the beds undoubtedly are represented but are not readily distinguishable. In New York, the Shoreham is characterized at its base by frequent limestone conglomerates and subsolifluction phenomena, such as are displayed along Roaring Brook, at Lowville, on Stony Creek (Denmark), and along the Deer River at Kings Falls; similar structures are less common in the succeeding Denmark member. Though the member is distinctly more shaly and less resistant than the underlying Hull formation, its differentiation from the overlying Denmark is principally on a faunal basis; it tends to be more shaly than the lower Denmark beds.

[79] P. E. Raymond: *Quebec and vicinity*, Geol. Surv. Canada, Guidebook 1 (1913) p. 40.

FAUNA: *Cryptolithus tesselatus* Green, guide fossil of the member, is usually accompanied by *Trematis terminalis* (Emmons) and *Prasopora orientalis* Ulrich, which are found also in the overlying Denmark member. Along Lake Champlain, *Dalmanella edsoni* Bassler, *Strophomena conradi* Hall and Clarke, and *Bucania punctifrons* Emmons are common associates (Pl. 10).

Denmark member of the Sherman Fall formation (new).—The Denmark member (Denmark Township, Lewis County, New York) is defined as including the limestones of the Sherman Fall formation of northwestern New York that overlie the Shoreham member of the formation. In Denmark Township, *Cryptolithus* is found at 25 feet above the base of the formation above High Falls, Stony Creek, and 20 feet above the base along the Deer River, just above Kings Falls. As a result of faulting, the Shoreham is again exposed half a mile farther up the river at the bend above the schoolhouse north of the stream, and there is continuous exposure of the Denmark member be-

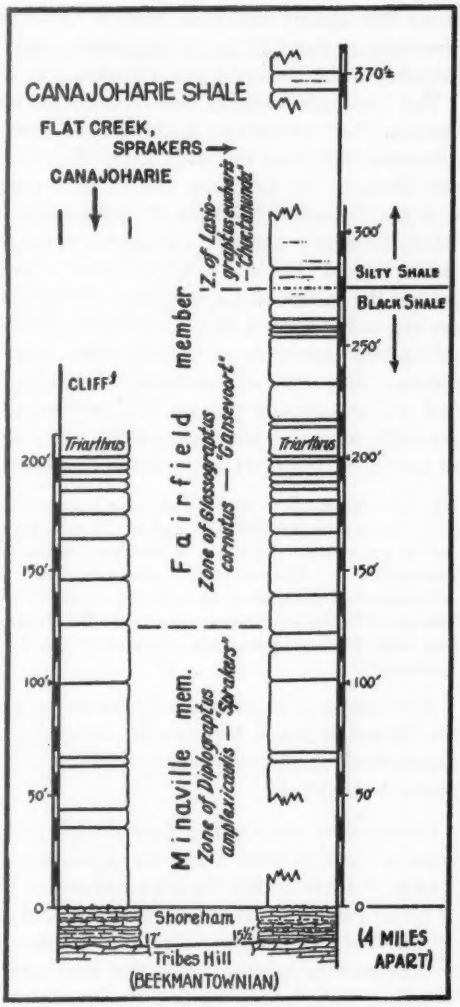


FIGURE 11.—*Sections along Canajoharie Creek and Flat Creek, south of Sprakers, New York*

The dark horizontal lines represent clay partings, believed to be thin metabentonites. The lower shales are poorly shown on Flat Creek, and the 202-foot horizon on Canajoharie Creek has been placed opposite the correlated horizon on Flat Creek.

tween this locality and High Falls at Copenhagen. The thickness of the Shoreham is about 30 feet in this region, and the remaining Sherman Fall included in the Denmark has a thickness of about 170 feet.

The Denmark member thus constitutes much the larger part of the Sherman Fall formation. Although the base of the member tends to be more resistant than the more shaly Shoreham member, the contrast is not distinct. As has been stated, the upper contact of the formation with the Cobourg is also poorly defined lithologically. The higher Denmark frequently contains calcareous claystones replete with specimens of the "fucoid" *Buthrotrephis* sp.; such beds are conspicuous in the lower part of the section at Cape Versey, Prince Edward County, Ontario, and are exposed in several localities in northwestern New York. Though subsolifluction structures are particularly frequent in the older Shoreham member, they are well developed in the upper Denmark at Trenton Falls, and are occasionally present in northwestern New York. The member normally comprises alternating shaly and coarse-textured limestones such as have been described as typical of the Sherman Fall formation.

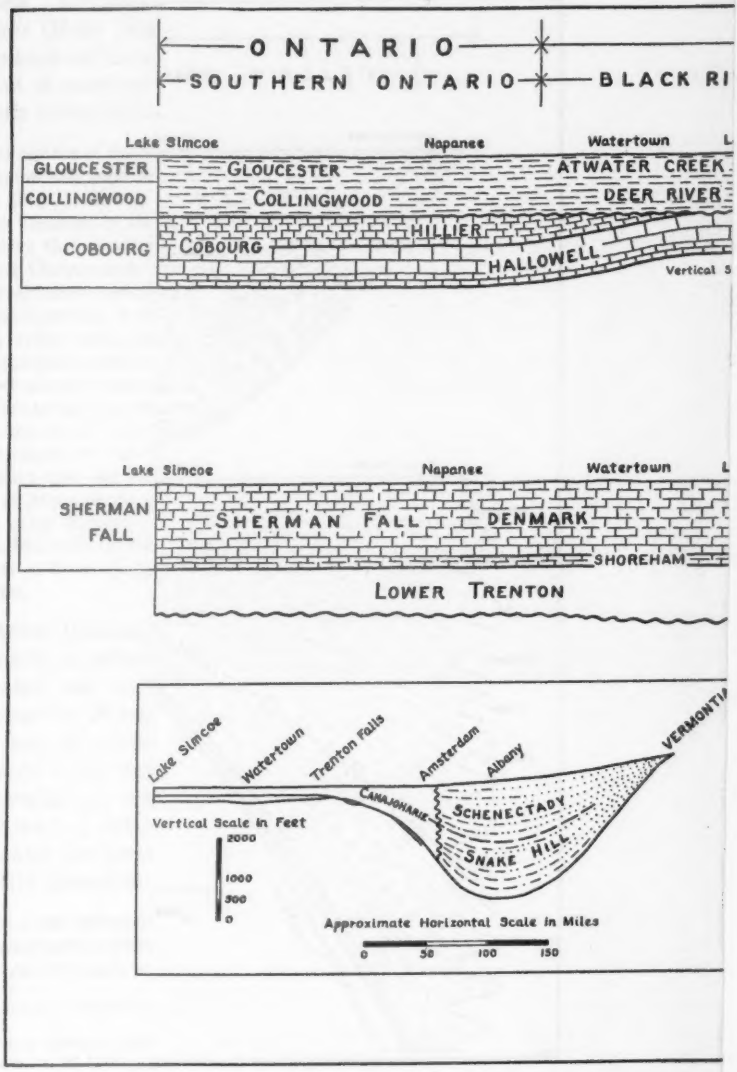
FAUNA: Inasmuch as it is this member that is well displayed in the Trenton Falls gorge and is thus the "typical Trenton," its most common fossils are such well-known and in some cases ubiquitous species as *Dalmanella* sp. cf. *D. rogata* (Sardeson), *Sowerbyella* sp., *Platystrophia trentonensis* McEwan, *Bellerophon corrugatus* Hall (=*Sinuites cancellatus* of authors, not of Hall), *Calymene senaria* Hall, and *Isotelus gigas* (Dekay); *Prasopora orientalis* Ulrich persists from the underlying Shoreham with *Trematis terminalis* (Emmons), and *Rafinesquina praecursor* Raymond is common.

Southeastward and eastward from the upper West Canada Creek valley, the Denmark passes through the Dolgeville interbedded facies into the Canajoharie shale, a formation that grades eastward into more coarsely clastic beds (Pl. 4).

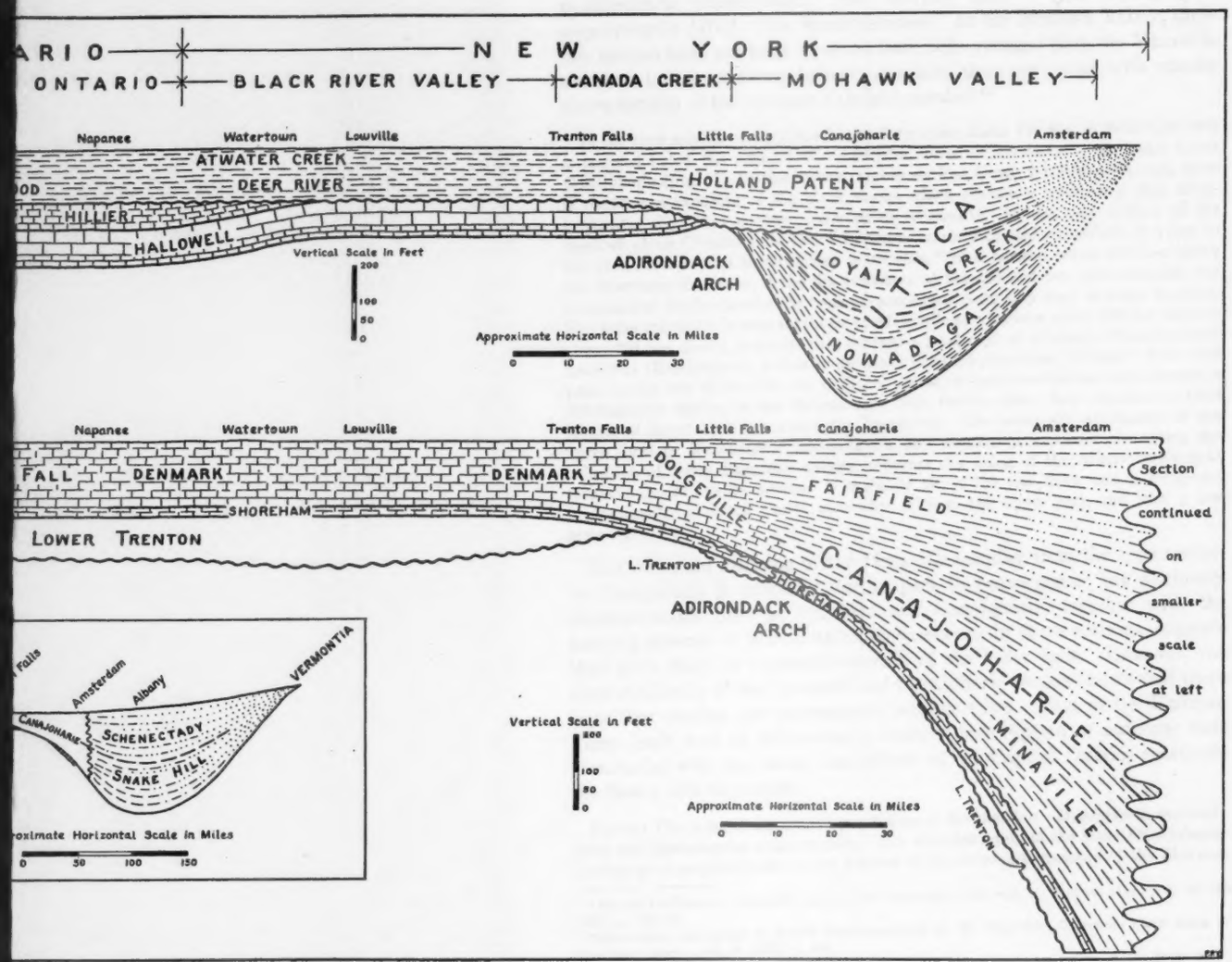
Canajoharie shale.—The Canajoharie formation (Canajoharie, Montgomery County, New York) comprises the older shales of the Mohawk Valley;[80] these overlie the lowest Sherman Fall Shoreham limestone, are of about Denmark (Sherman Fall) age, and are overlain by similar shales of the Utica formations. In the type section (Fig. 11), the formation is conveniently separated into two members, the Minaville and Fairfield members; though the beds are lithologicaly similar, their faunal differences are sufficient to make them useful in interpretation of equivalent beds.

Minaville member of the Canajoharie formation (new).—The Minaville or lower Canajoharie member (Minaville, Florida Township, Montgomery County, New York) is defined as including the two lowest zones of the

[80] Rudolf Ruedemann: *Lower Siluric shales of the Mohawk Valley*, N. Y. State Mus., Bull. 162 (1912) p. 28.



RESTORED SECTIONS OF HIGHER TRENT



TORED SECTIONS OF HIGHER TRENTON FORMATIONS FROM CENTRAL ONTARIO TO THE HUDSON VALLEY

five assigned to the formation by Ruedemann,[81] those of *Mesograptus mohawkensis* (Ruedemann) (the Morphy zone[82]) and *Diplograptus amplexicaulis* (Hall) (the Sprakers zone). In the Mohawk Valley, these two species have not been reported from beds younger than the Minaville member, but in northern Lake Champlain, they are found with species characteristic of the younger Fairfield member.[83]

In the type section of the Canajoharie formation, about 125 feet of Minaville beds is exposed below the zone of *Glossograptus cornutus* Ruedemann, the basal upper Canajoharie (Fig. 11). In this section, and along Flat Creek, 3 miles to the east, there is continuous exposure of the black shales, which contain a number of thin metabentonitic clays that produce conspicuous reentrants. In the type section of the member along Chuctanunda Creek between Amsterdam and Minaville, 17 miles to the east, *Mesograptus mohawkensis* is common[84] at a horizon about 500 feet above the Shoreham limestone, if the dip continues at the 100 feet per mile rate that can be measured farther north; the beds are somewhat more silty than in lower horizons. The same graptolite is seen southeast of Minaville at a horizon about 250 feet higher; about 200 feet above, in shales that contain a good deal of siltstone, *Climacograptus spiniferus* (Ruedemann), normally an upper Fairfield graptolite, is found. From this point to the top of the hill, the beds are coarse, impure sandstones, and bluestones lithologically similar to the Schenectady beds farther east; they complete a total section of about 1200 feet above the limestones. The uncertain significance of the upper limit of *Mesograptus mohawkensis*, and insufficient exposure preventing the collection of other diagnostic species, prevents the fixing of the Minaville-Fairfield contact; the Minaville member is probably about 750 feet thick and is composed predominantly of block shales, somewhat silty in the upper part, and with a few metabentonites.

The westward thinning of the Minaville member from the type section to Canajoharie is probably due in part to convergence; the obviously disconformable base at Sprakers and Canajoharie, together with the seeming absence of *Mesograptus mohawkensis* in those sections, suggests that there may be westward overlap of the lower beds. However, the close similarity of the Sprakers and Canajoharie section shows that there is neither overlap nor convergence between them. East of the Hoffman Ferry fault west of Schenectady, there is interruption of outcrop; beds homotaxial with the lower Canajoharie of the Capitol District constitute the Snake Hill formation.

FAUNA: The most characteristic graptolites of the member—*Mesograptus mohawkensis* and *Diplograptus amplexicaulis*—seem abundant only in the lower Canajoharie; *Diplograptus amplexicaulis* is also present in the Denmark member of the Sherman

[81] Rudolf Ruedemann: *Graptolite zones of the Ordovician shale belt*, N. Y. State Mus., Bull. 227-228 (1921) p. 122-126.

[82] Geographic zone names in Rudolf Ruedemann and G. H. Chadwick: *Ordovician black shales of New York*, Science, vol. 81 (1935) p. 400.

[83] Rudolf Ruedemann: *Age of the black shales of the Lake Champlain region*, N. Y. State Mus., Bull. 227-228 (1921) p. 111.

[84] Rudolf Ruedemann: *Lower Siluric shales of the Mohawk Valley*, N. Y. State Mus., Bull. 162 (1912) p. 17.

Fall formation southwest of the Adirondacks. Other common graptolites are *Corynoides calicularis* Nicholson, equally abundant in the succeeding Fairfield member, and *Lasiograptus eucharis* (Hall), which ranges as high as the Utica shales. In association are typical lower Sherman Fall species such as *Prasopora orientalis* Ulrich, *Calymene senaria* Hall, and forms such as *Leptobolus insignis* Hall, *Ulrichia bivertex* (Ulrich) and *Primitiella unicornis* Ulrich that are also in other shale members.

Fairfield member of the Canajoharie formation.—The Fairfield shale [85] (Fairfield Township, Herkimer County, New York), or upper Canajoharie, is defined as comprising the three upper zones, as designated by Ruedemann; the Fairfield member extends westward as a gradationally overlapping tongue of the formation, passing through the Dolgeville interbedded facies into the upper Denmark member of the Sherman Fall formation. It is exposed in a number of localities in the type area.

In the type section of the Canajoharie formation, the zone of *Glossograptus cornutus* Ruedemann (Gansevoort zone,[86] from Gansevoort, Saratoga County)—the basal Fairfield—is exposed continuously for about 150 feet above the Minaville. About 60 feet from the base of the member is a conspicuous set of five metabentonites, inclosing 15 feet of black shales containing *Triarthrus becki* Green. The same 15 foot band may be seen along Flat Creek, above Sprakers, and succeeding exposures along the stream bed extend continuously for another 100 feet.

About 150 feet from the base of the member, the beds become interbedded black shales and gray-weathering silty shales; there are metabentonites in these beds, as well as in an isolated exposure farther up the stream, extending to about 250 feet in the section of the Fairfield member. The silty shales belong in the zone of *Lasiograptus eucharis* (Hall)—the Chuctanunda zone (Chuctanunda Creek, south of Amsterdam). Exposures from which *Climacograptus spiniferus* Ruedemann, guide fossil for the third zone, or Fort Plain, is listed, are from 400 to 450 feet from the base of the Canajoharie formation, or more than 275 feet from the base of the Fairfield member; thus the *Lasiograptus* zone has a thickness of less than 125 feet, and the zone of *C. spiniferus* is not limited upward, but exceeds 50 feet. The thickness of the Fairfield member in the Canajoharie region thus exceeds 275 feet, and is probably about 400 feet.

In the Minaville section, which has been discussed, the upper part of the section is incompletely exposed, but the thickness of the Fairfield member, which is composed of silty and sandy beds, is at least 450 feet thick, with the upper limit uncertain. It is believed that the member is represented farther to the east by the Schenectady beds of the Capitol district.

FAUNA: *Glossograptus cornutus* (Ruedemann) has been described as characterizing the lowest zone of the Fairfield member, and as extending through 150 feet of beds at Canajoharie Creek; other species of the genus are found in higher beds. At Flat Creek, the beds in which *Lasiograptus eucharis* (Hall), a long ranging form, are most abundant are the silty beds at the top of the continuous section. This (Chuctanunda) zone is about 125 feet thick. *Climacograptus spiniferus* (Ruede-

[85] Lardner Vanuxem: *Geology of New York. Part III, comprising the survey of the third geological district* (1842) p. 56. Albany.

[86] Rudolf Ruedemann and G. H. Chadwick: *Ordovician black shales of New York*, Science, vol. 81 (1935) p. 400.

mann) is abundant in the overlying (Fort Plain) zone and not known to be frequent other than in these beds.

Diplograptus strictus Ruedemann is characteristic of the member, but it is known from other horizons; *D. vespertinus* Ruedemann is abundant in the upper zone and has not been reported in other members; *D. macer* Ruedemann has a similar range, but it is less common; *Corynoides calicularis* Nicholson is common, but equally so in the underlying Minaville. Among species of other classes, *Triarthrus becki* Green is most significant, for it seems characteristic of the upper Canajoharie, and contrasts with *T. eatoni* Hall of the succeeding Utica.

Dolgeville facies of the Sherman Fall formation.—The term Dolgeville beds (Dolgeville, Herkimer County, New York) was applied by Cushing [87] to the strata previously termed the "Trenton-Utica passage beds." The facies is one of interbedded limestone and shale overlying dominantly limestone beds, and underlying the gradationally overlapping shales of the Fairfield member. The beds are of rather barren, black, fine-textured, thin limestones, with black shale interbeds of variable thickness. In distribution, they are limited to a belt extending from north of Norway, Herkimer County, to the vicinity of St. Johnsville; the thickness is reported as from 50 to 100 feet, the thicker sections being in the west. The facies is absent at Gravesville, where the whole of the Denmark is limestone, and at Canajoharie, where black shales lie directly on the lowest Sherman Fall limestone.

In the type section, the upper part of the facies bears *Climacograptus spiniferus* Ruedemann, *Glossograptus postremus* Ruedemann, *Lasiograptus eucharis* (Hall), and *Triarthrus becki* (Green),[88] a faunule indicating that it is the western continuation of the upper (Fort Plain) zone of the Fairfield member—the upper Canajoharie. In addition, there are certain ubiquitous Trenton species and other forms distinctive of the Dolgeville alone.

Insufficient exposure makes difficult the demonstration of the stratigraphic relations of the Dolgeville. The classification of its upper limit as the top of the Sherman Fall is dependent on the correlation of the lower Utica, to be discussed later. It is apparent that it is younger than basal Denmark, because in the west, limestones of that age underlie it, and in the east, the Shoreham member of the Sherman Fall is overlain disconformably by the basal Canajoharie; moreover, the fauna of at least the typical Dolgeville is upper Canajoharie. The beds are considered to represent the intermediate facies below the westwardly gradationally overlapping and thinning upper Canajoharie. Beds of Dolgeville facies in eastern sections are presumably equivalent to older Canajoharie beds, but that has not been demonstrated. Inasmuch as the lower Canajoharie

[87] H. P. Cushing, *in* W. J. Miller: *Geology of the Remsen quadrangle*, N. Y. State Mus., Bull. 126 (1909) p. 21.

[88] Rudolf Ruedemann: *Fauna of the Dolgeville beds*, N. Y. State Mus., Bull. 227-228 (1921) p. 100-101.

is believed to overlap easward to Canajoharie, the lower Denmark may similarly overlap eastward, rather than passing through an interbedded facies.

Snake Hill formation.—The Snake Hill beds (Snake Hill, south of Saratoga Lake, New York) were defined[89] to comprise the Middle Ordovician silty shales of the Hudson Valley that were considered equivalent to the Canajoharie shale, and had been previously identified with the Magog shale of Quebec.[90] The upper and lower contacts of the formation are not known, and its thickness has been estimated as being about 3000 feet.[91]

The Snake Hill formation crops out in a belt extending northward along the Hudson River from the northeastern part of the Helderberg Plateau. Similar beds have been described farther south on the northwest side of the Highlands—the Reading Prong of the New England Upland—in which region they overlie limestones of Black River and low Trenton age.

FAUNA: The Snake Hill fauna has three elements. First, there are graptolites such as *Corynoides calicularis* Nicholson, *Diplograptus amplexicaulis* (Hall), and *Lasiograptus eucharis* (Hall), found farther to the west in the lower Canajoharie shale; others, such as *Climacograptus caudatus* Lapworth, are found in the Magog shale of Quebec. Second, there are many species of molluscs, particularly gastropods and pelecypods, many of which are distinctive of, and limited to, the formation, although such Trenton forms as *Tetranota bidorsata* (Hall) and *Sinuites cancellatus* (Hall) are included. Third, there are brachiopods that suggest a correlation with the lower and middle Trenton, *Trematis terminalis* (Emmons), *Dalmanella rogata* (Sardeson), *Sowerbyella* sp., *Vellamo americanus* (Whitfield), and *Parastrophina hemiplicata* (Hall) being typical; trilobites such as *Eoharpes ottawaensis* (Billings), *Pterygometopus callicephalus* (Hall), *Calymene senaria* Hall, and *Cryptolithus tesselatus* Green accord with this correlation.

Ruedemann[92] has expressed the view that the Canajoharie and Snake Hill occupied the Chazy and Levis troughs, respectively, during Middle Ordovician time, and were separated by a barrier. It is the writer's opinion that the Snake Hill represents an eastern, more sandy, facies of the Canajoharie black shale, and consists of the initial deposits of clastic rocks resulting from the Vermontian (middle Trenton) orogeny (Pl. 4). In support of this view, the lower Canajoharie (Minaville) fauna is found within the Snake Hill; the Snake Hill forms that are absent from the Canajoharie are those in the silty facies. The Canajoharie beds thicken and become more coarsely clastic eastward along the Mohawk Valley. There is no known reasonable source for the large volume of Canajoharie

[89] *Op. cit.*, p. 58.

[90] Rudolf Ruedemann: *Graptolites of New York: Part II, Graptolites of the higher beds*, N. Y. State Mus., Mem. 11 (1908) p. 29.

[91] Rudolf Ruedemann: *Geology of the capital district*, N. Y. State Mus., Bull. 285 (1930) p. 218.

[92] Rudolf Ruedemann: *Alternating oscillatory movement in the Chazy and Levis troughs of the Appalachian geosyncline*, Geol. Soc. Am., Bull., vol. 40 (1929) p. 410.

clastics if they are conceived as having been deposited to the west of a barrier separating them from a source farther east than an intervening sea. Beds lithologically and faunally like the Snake Hill in the district northwest of the Highlands of the Hudson lie on limestones like those by the Adirondacks,[93] and outside the belt of Taconic thrusting. It is anomalous to this interpretation that the Snake Hill has been mapped as infolded with Normanskill shale near Albany,[94] for the latter has been thrust far from the east in the Taconic orogeny; the exposures are in the belt of intense folding and thrusting.

Schenectady formation.—The Schenectady formation (Schenectady, New York)[95] comprises the blue-gray, calcareous sandstones and intercalated shales that underlie the Indian Ladder beds of Eden age in the lower Mohawk Valley. The beds extend in a belt across the Mohawk River east of the Hoffman Ferry fault, through Schenectady into Saratoga County. The formation is composed of interbedded blue-gray, calcareous sandstones with intercalated dark-gray, arenaceous shale. In the upper part, heavy ledges are common, and some have shrinkage cracks, mud-pebble conglomerates, plunging cross-bedding, and lensing. The thickness of beds underlying the Indian Ladder beds and overlying the Trenton limestones in the vicinity of Altamount, south of Schenectady, is about 3000 feet.[96] It is known that the thickness of the eastwardly expanding lower Canajoharie (Minaville) is about 750 feet south of Amsterdam, and it is probable that the equivalent beds are more than a thousand feet thick at Altamount, and they may exceed that amount. Thus, the Schenectady must be about 1500 feet thick.

FAUNA: The formation contains such distinctive Trenton fossils as *Trocholites ammonius* Conrad, *Spyroceras bilineatum* (Hall), *Plectorthis plicatella* (Hall), *Dalmanella rogata* (Sardeson), *Cryptolithus tesselatus* Green, and *Isotelus gigas* Dekay. The upper beds contain eurypterids that are unknown in other strata. But most significant is the presence to within a few hundred feet of the top of the Schenectady formation of such characteristic upper Canajoharie (Fairfield) graptolites as *Diplograptus vespertinus* Ruedemann, *Climacograptus spinifer* Ruedemann, *Diplograptus strictus* (Ruedemann), and *Corynoides calicularis* Nicholson, and the trilobite *Triarthrus becki* Green. The upper Canajoharie classification is supported by the fact that lithologies similar to those in the Schenectady invade the upper part of the Canajoharie in the section above Minaville.

The lithology of the upper Schenectady suggests its deposition in near-shore, shallow-water environments. It is probable that the area became

[93] Florrie Holzwasser: *Geology of the Newburgh quadrangle*, N. Y. State Mus., Bull. 270 (1926) p. 60-64.

[94] Rudolf Ruedemann: *Geology of the Capital district*, N. Y. State Mus., Bull. 285 (1930) map.

[95] Rudolf Ruedemann: *Lower Siluric shales of the Mohawk Valley*, N. Y. State Mus., Bull. 162 (1912) p. 37.

[96] *Ibid.*

graded prior to Utica time, and that deposition ceased about the close of Canajoharie-Sherman Fall time.

Cumberland Head formation.—The term Cumberland Head shales (Cumberland Head, Clinton County, New York) was used informally by Cushing,[97] in referring to the interbedded limestones and shales between the limestone and black shale of Trenton age along northern Lake Champlain. The Cumberland Head may be defined as including the argillaceous limestones and limestone-bearing black shales succeeding the lowest Sherman Fall Shoreham limestone and underlying the Stony Point black shale in the type region. The beds are quite fully exposed in the section discussed by Cushing on Hero Island, Grand Isle County, Vermont, 2 miles southeast of Cumberland Head. North of Rockwells Bay, 30 feet of beds composed predominantly of 8 and 12 inch beds of gray, argillaceous limestone with intercalated dark shale is overlain by 115 feet of beds in which black shales are predominant, but limestone interbeds abundant, particularly in the lower part; thus, there is 145 feet of Cumberland Head beds exposed. The unexposed lower portion is probably not of great thickness, and farther south, north of McBride Bay, the Shoreham limestone crops out. The succeeding Stony Point black shales have very few limestone interbeds, extend northward to beyond the Cumberland Head Ferry slip, and have an exposed thickness of 215 feet.

FAUNA: The fauna of the Cumberland Head beds in a section in Panton Township, Addison County, Vermont, nearly 40 miles south of Cumberland Head, has been listed by Ruedemann.[98] The presence of *Cryptolithus tesselatus* Green in the shales at the base of the "transition series" suggests that the latter extend down to the Shoreham beds. Both in this section and on Hero Island, the fauna of the limestones is large, and contains common Trenton species. The graptolites from the Cumberland Head shales at Panton include *Diplograptus amplexicaulis* (Hall), *Corynoides calycularis* Nicholson, *Mesograptus mohawkensis* (Ruedemann), and *Climacograptus strictus* Ruedemann—forms evidencing their lower Canajoharie (Minaville) age; the presence of the upper Canajoharie *Climacograptus spiniferus* Ruedemann exemplifies the somewhat varying range of the forms. The Cumberland Head beds at this locality are about 100 feet thick,[99] and are overlain by 400 feet of black shale.

Inasmuch as the Cumberland Head formation lies on the lowest Trenton Shoreham limestone, contains graptolites of lower Canajoharie (Minaville) age, and underlies the Stony Point black shale of upper Canajoharie (Fairfield) age, the beds are of about the age of the lower Denmark member of the Sherman Fall formation of western New York.

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[97] H. P. Cushing: *Geology of the northern Adirondack region*, N. Y. State Mus., Bull. 95 (1905) p. 375.

[98] Rudolf Ruedemann: *The age of the black shales of the Lake Champlain region*, N. Y. State Mus., Bull. 227-228 (1921) p. 108-111.

[99] E. J. Foyles: *Stratigraphy of the townships of Addison, Panton, and southwestern Ferrisburg, Vermont*, Vt. State Geol., 15th Rept. for 1925-1926 (1927) p. 8.

The black shale is believed to overlap gradationally northward; thus, the top of the limestone should be younger at the north end of the lake than at the south. It is concordant that black shale lies directly on Shoreham in the lower Mohawk Valley, within 35 feet of typical Shoreham at Glens Falls, that about 100 feet of beds intervene at Panton, and that the typical Cumberland Head is about 150 feet thick.

Stony Point formation.—The Stony Point shale (Stony Point, Clinton County, New York, near the Quebec border) was described by Ruedemann [100] as a black shale cropping out near Rouses Point, New York, and containing a fauna identified as of the age of the upper Canajoharie shale of the Mohawk Valley. The formation overlies the Cumberland Head shaly limestone, and has an exposed thickness of 215 feet in the section on Hero Island, Vermont, which has been discussed. It is the prevalent black shale in the northern Lake Champlain region, and in southern Quebec is overlain by the Iberville shale of questionably Utica age.[101] The Stony Point is about 500 feet thick in its type area.

FAUNA: The typical Stony Point shale contains *Climacograptus spiniferus* Ruedemann, *Glossograptus quadrimucronatus* (Hall), and *Triarthrus becki* Green, species indicative of its later Canajoharie (Fairfield) age. The black shale overlying the Cumberland Head in Panton, Vermont, contains *Glossograptus cornutus* Ruedemann, and has also been referred to the upper Canajoharie. It is apparent that *Cryptolithus tesselatus* Green ranges far above the lowest Sherman Fall in this region, for, in addition to being known in the Snake Hill formation, it is abundant in the Stony Point beds at Panton.

Lacolle conglomerate.—The Lacolle conglomerate (Lacolle, Quebec, north of Rouses Point, New York) was described by Clark [102] as lying unconformably on Beekmantownian, Chazyan, and lower Mohawkian beds in a curving belt extending north and northwest of the International Boundary, and as overlain by the Stony Point shale. The formation is composed of boulders up to several feet in diameter, in a sandy, calcareous matrix; the blocks are mostly of Beekmantownian and Chazyan dolomites and limestone, but also include fragments bearing *Cryptolithus tesselatus* Green, indicating that the lowest Sherman Fall had been deposited prior to the deposition of the conglomerate. Inasmuch as the overlying Stony Point shale seems of late Sherman Fall age, the Lacolle is of post-early Sherman Fall, pre-late Sherman Fall, and equivalent to the lower Canajoharie shale of the Mohawk Valley, and to the lower part of the Denmark

[100] Rudolf Ruedemann: *The age of the black shales of the Lake Champlain region*, N. Y. State Mus., Bull. 227-228 (1921) p. 112.

[101] T. H. Clark: *Structure and stratigraphy of southern Quebec*, Geol. Soc. Am., Bull., vol. 45 (1934) p. 5.

[102] *Ibid.*

T. H. Clark and H. W. McGerrigle: *Lacolle conglomerate: a new Ordovician formation in southern Quebec*, Geol. Soc. Am., Bull., vol. 47 (1936) p. 665-674.

member west of the Adirondacks. The conglomerate probably reflects the rise of the Adirondack axis at this time.

The disconformity above conglomerate-bearing limestone a little older than the Lacolle, at Inghams Mills, and Sprakers, on the opposite side of the Adirondacks, has been mentioned. It is believed significant that these structural changes in the Adirondack region are concurrent with the advent of orogenic movements east of the region, as expressed in the sudden incursion of clastics in early Denmark-Canajoharie time.

Rysedorph conglomerate.—The Rysedorph conglomerate (Rysedorph Hill, Rensselaer County, New York)[103] is a formation, within the belt of Taconic overthrusting east of Albany, that has been a subject of discussion, both with respect to origin of the beds, and to the source of the included pebbles.[104] The formation is distributed linearly northward and southward from the type locality, and is known also in separated belts to the east.[105] Although it has been suggested that some of the beds mapped as Rysedorph are fault blocks along a line of overthrusting, the formation certainly includes deposited conglomerate later disturbed by structural movements. The formation includes older pebbles, but those pertinent to the present discussion are of Trenton age, and of two sorts.

The most abundant of the pebbles in the Rysedorph are of dark-gray, crystalline limestone, containing *Prasopora orientalis* Ulrich, *Triplecia nucleus* (Hall), and *Protozyga exigua* (Hall)—Sherman Fall forms in western New York—suggesting that the conglomerate is post-early Sherman Fall age; *Parastrophina hemiplicata* (Hall) and *Dalmanella rogata* (Sardeson), species of longer range, are associated with *Hesperorthis tricenaria* (Conrad), *Phragmolites compressus* Conrad, and *Dolerorthis pervetus* (Conrad)—forms considered characteristic of the lower Trenton adjacent to the Adirondacks. A second lot of pebbles, of very dark-gray, fine-textured, hard limestone, are relatively uncommon, but contain a most interesting fauna. That they are approximately synchronous with the first is shown by the presence of a number of common species. They contain an additional element unknown in the typical Trenton, with such species as *Leptelloidea pisum* (Ruedemann), *Christiania trentonensis* Ruedemann, *Remopleurides linguatus* Ruedemann, and *Ampyx hastatus* Ruedemann, some of which are present in the Chambersburg limestone of Virginia, in the upper part, which seems to be of lowest Trenton age.

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[103] Rudolf Ruedemann: *Trenton conglomerate of Rysedorph Hill*, N. Y. State Mus., Bull. 49 (1901) p. 1-114.

[104] Rudolf Ruedemann: *Geology of the capital district*, N. Y. State Mus., Bull. 285 (1930) p. 104-113.

[105] Rudolf Ruedemann: *personal communication.*

Ruedemann has described the Rysedorph as interbedded in the base of the Snake Hill formation, and containing faunas belonging in a trough separated by an intervening axis from that in which the eastern Adirondack Trenton was laid down. The writer has expressed the view that the Snake Hill is not exotic, and it is his view that the Rysedorph is, similarly, a formation deposited in beds continuous with the eastern Adirondack Trenton. In support of this view, most of the species in the prevalent pebbles are the same as those in the typical Trenton. Secondly, the two lots of pebbles contain several forms common to both, and among them *Remopleurides linguatus* and *Leptelloidea pisum*, not known in the typical Trenton. Thus, pebbles that have typical Trenton forms have exotic species, which are in turn common to the pebbles that have a larger foreign element. Thirdly, the Chambersburg limestone, which is said to contain some of the distinctive species, is within a stratigraphic sequence containing other formations faunally and lithologically similar to equivalent beds adjacent to the Adirondacks, whereas the representatives of the pre-Trenton in the eastern trough east of New York were lithologically and faunally dissimilar to the Chambersburg associates. Moreover, the older pebbles reported from the Rysedorph have been identified with the normal Adirondack formations rather than with the equivalent beds that have been overthrust from the eastern trough.

It is believed that the pebbles in the Rysedorph were derived from limestones deposited in an eastward extension of seas contiguous to the Adirondack region. The faunal differences seem no greater than those from other separated areas of Trenton sediments that can be demonstrated to be continuous. The beginning of movements to the east that resulted in the great influx of clastic sediments into the eastern Adirondack region in Sherman Fall time may have exposed the beds to erosion. Undoubtedly faulting has had much influence in placing the Rysedorph in its present relationships, just as blocks containing *Nidulites* sp., another Chambersburg form, have been displaced along faults at Quebec.[106]

FORMATIONS OF COBOURG AGE

Cobourg limestone.—The term Cobourg limestone[107] (Cobourg, Ontario) replaced "Picton limestone", which had been "applied to the heavy-bedded limestones with the gastropod fauna, and the underlying, thinner-bedded limestone with *Rafinesquina deltoidea*" exposed at Picton, Prince Edward County, Ontario;[108] the latter name had been pre-

[106] H. M. Ami: *Notes on fossils from Quebec City, Canada*, Ottawa Nat., vol. 8 (1894) p. 82-90.

[107] P. E. Raymond: *A contribution to the description of the fauna of the Trenton group*, Geol. Surv. Canada, Bull. 31 (1921) p. 1.

[108] P. E. Raymond: *Trenton group in Ontario and Quebec*, Geol. Surv. Canada, Summ. Rept. for 1912 (1914) p. 345-349.

occupied. The formation is separable into two members, which were distinguished by Raymond, and are here designated the Hallowell and the Hillier members. East of the Adirondack Arch it is represented in a part of the Utica formation.

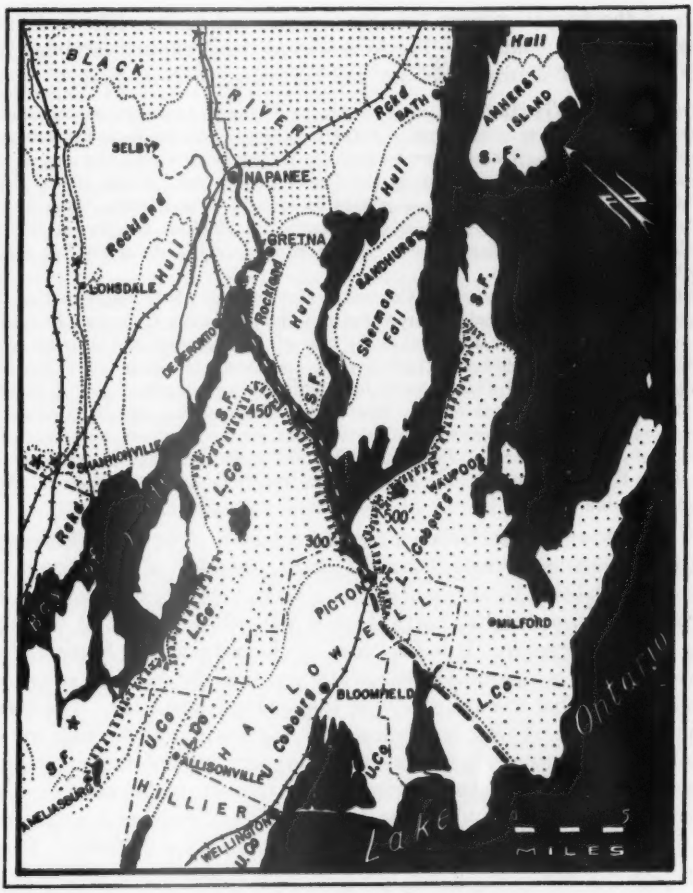
Plate 4 portrays the lateral relations of beds of Cobourg age.

Hallowell member of the Cobourg formation (new).—The Hallowell limestone (Hallowell Township, Prince Edward County, Ontario) is here defined as the lower Cobourg limestone of earlier reports; the type section is at Picton, within the township. The member is the zone of *Rafinesquina deltoidea* (Conrad), a species abundant in the upper part of the member, less common in the lower, and of which typical specimens are quite unknown in other formations or members. The lower boundary of the member is arbitrarily drawn at the base of a zone containing *Pasceolus globosus* Billings (*"Ischadites* sp.") ; the species is found at a similar position a mile east of Ameliasburg, Prince Edward County, and in some abundance 200 feet above the base of the Sherman Fall formation on Lowville Mill Creek, New York. The top of the member is distinguished from the overlying Hillier member in that it is composed of heavy-ledged, coarse-textured limestones in which *Rafinesquina deltoidea* is normally abundant; the overlying beds are argillaceous, and buff, nodular-weathering.

The member constitutes the whole of the originally described section at Picton;[109] *Hormotoma trentonensis* Ulrich and Scofield and *Fusispira subfusiformis* (Hall) are frequent in the upper beds of the Hallowell, and their presence led to a misinterpretation of the section. The Picton section lies on the east side of a monocline (Fig. 12) that brings the Hallowell member far above the Hillier member outcropping to the west. The Hillier member was recognized and properly placed in other sections in the original description.

The lower part of the Hallowell member does not differ distinctly in its lithology from that of the subjacent Sherman Fall beds. The upper part is composed, in northwestern New York and southern Ontario, of gray, medium- to coarse-textured, massive limestones, practically lacking intercalated shales; it forms the most resistant strata in the Trenton group. The contrast with the more argillaceous overlying Hillier member is responsible for the formation of a prominent cuesta at the top of the Hallowell wherever it is exposed, from Trenton Falls to its disappearance under heavy drift cover in Northumberland County, Ontario. High Falls, Copenhagen, New York, along the west side of the Black River Valley, is one of several falls dropping from this horizon. The upper

[109] *Op. cit.*, p. 345.



PICTON - NAPANEE REGION, ONTARIO

TRENTON	COBOURG HILLIER	U. Co.	70'	LOWER COBOURG SCARP-ELEVATION	500'
	COBOURG HALLOWELL	L. Co.	100'		
	SHERMAN FALL	S.F.	200'	PRE-CAMBRIAN INLIERS	
	HULL	Hull	80'		
	ROCKLAND	Rcke	45'	PICTON MONOCLINE	
BLACK RIVER			160'		

FIGURE 12.—*Geological map of the Picton-Napanee area, southeastern Ontario*
The Picton monocline produces offset in the lower Cobourg escarpment, and in the course of the Bay of Quinte.

part of the formation caps the many northward-facing cliffs in Prince Edward County, Ontario. The thickness of the Hallowell is about 100 feet throughout southern Ontario and northwestern New York.

DISTRIBUTION: The Hallowell member of the Cobourg formation is continuous from Georgian Bay on Lake Huron to Trenton Falls and Gravesville in the valley of West Canada Creek. The member is absent in the Mohawk Valley and east of the Adirondacks, the equivalent beds, in the former region, being shales of the Utica formation. The Lower Cobourg is present in sections near Ottawa, Ontario, but seems absent at the Lake Clear infaulted outlier in Renfrew County, where the Collingwood black shale lies above a covered interval, and is about 175 feet above the basal Sherman Fall.

FAUNA: *Rafinesquina deltoidea* (Conrad) is characteristic of the upper part of the member, and is not typically represented outside the Lower Cobourg; *Pasceolus globosus* Billings is locally abundant in the base of the Hallowell, and is found occasionally within the member. These species are shown on Plate 10. *Dinorthis iphigenia* (Billings) and *Platystrophia longicardinalis* are abundant and diagnostic of the upper beds in northwestern New York. Much of the remaining fauna is composed of ubiquitous species of the Trenton that, for the most part, were originally described from the Sherman Fall formation. The gastropods that characterize the overlying Upper Cobourg (Hillier) member are less frequent in the Hallowell, but are locally abundant.

Hillier member of the Cobourg formation (new).—The Hillier limestone (Hillier Township, Prince Edward County, Ontario) is here defined as the Upper Cobourg limestone of earlier reports, the member being exposed for several miles along the north shore of Lake Ontario, west of Wellington, Hillier Township. It is the "zone of *Hormotoma* and *Fusispira*" of Raymond, and is separable lithologically and faunally from the subjacent Hallowell member and the overlying Collingwood formation. The lower boundary of the member is lithologically distinct in that the beds are of argillaceous limestones, in contrast to the massive and resistant crystalline limestones of the top of the Hallowell. Some transition takes place through a thickness of 20 feet, and the top of the Hallowell member is considered as the top of the highest ledges containing *Rafinesquina deltoidea*. There is similar transition at the top into the black shales of the Collingwood formation in central Ontario, the guide fossil of that formation, *Ogygites latimarginatus* (Hall) passing downward into the limestones, not only in Ontario, but also in northwestern New York, where the Hillier lies disconformably below the Collingwood Deer River shales.[110]

DISTRIBUTION: The Hillier member has a thickness of 60 to 70 feet throughout central and southern Ontario, and into northwestern New York. The thickness diminishes rapidly southeast of Copenhagen, in northern Lewis County, New York, and, though exposures are few, it is believed to disappear within the county, for it is absent in northern Oneida County, where the Upper Utica (Holland Patent) lies with disconformity on the Hallowell member of the Cobourg. The member also seems

[110] G. Marshall Kay: *Trenton group in northwestern New York: stratigraphy of the lower and upper limestone formations*, Am. Jour. Sci., 5th ser., vol. 26 (1933) p. 5-14.

absent on Manitoulin Island, north of Lake Huron, but reappears in northern Michigan, where the lithology is similar to that in central Ontario—very light-gray, marly limestone; in southeastern Ontario and New York, the member is composed of darker-colored limestone with shaly interbeds.

FAUNA: Although *Hormotoma trentonensis* Ulrich and Scofield and *Fusispira subfusiformis* (Hall) are among the most characteristic fossils in the Hillier member, they range downward into the Hallowell member. Similarly, *Ogygites latimarginatus* (Hall), frequent in the uppermost beds, is more distinctive of the Collingwood. Among the species that have been collected frequently in the member and that are not known elsewhere, are the brachiopods *Strophomena humerosa* Raymond, *Leptelloidea gibbosa* (Winchell and Schuchert), *Pseudolingula cobourgensis* (Billings), *Platystrophia globosa* MacEwan, and *Rafinesquina* sp. *Cyclospira bisulcata* (Emmons) is common in the member, but locally abundant in the Hallowell and Collingwood. The cephalopods *Probillingsites primus* Fritz and *Ephippiorthoceras sigmoidale* Fritz are characteristic, and *Ceraurinus marginatus* Barton is a frequent trilobite. In addition, there are a number of long ranging Trenton species, some of which, such as *Trochonema umbilicatum* (Hall), are more characteristic of this horizon than of any other. Some of these forms are shown in Plate 10.

In the Mohawk Valley, black shales overlying the Sherman Fall Canajoharie shales and underlying the Upper Utica shale of Collingwood-Gloucester age comprise the Lower and Middle Utica and are evidently of Cobourg age.

Liskeard formation.—The Liskeard formation (New Liskeard, Lake Timiskaming, Ontario) comprises the Trenton rocks in the Lake Timiskaming region, on the Ontario-Quebec boundary.[111] The name Haileybury limestone had earlier been applied,[112] but was pre-occupied. The formation lies with great unconformity on the irregular surface of the pre-Cambrian in the district. The lower part is composed of 50 feet of red shale, overlain by 8 feet of sandstone; the succeeding red and green shales have a thickness of about 140 feet, and are fossiliferous in the upper part. The upper 40 feet of the formation, dark-gray limestone, weathering with a pitted surface, contains a fauna that is most similar to that of the upper Cobourg Stewartville dolomite of the Mississippi Valley. The total thickness of the formation is about 300 feet, and it is probably overlain by the Wabi formation, of later Clinton Silurian age.

FAUNA: The Liskeard formation contains, in the upper part, *Receptaculites oweni* Hall, *Halysites quebecensis* Lambe, *Fusispira nobilis* Ulrich and Scofield, *Maclurina cuneata* (Whitfield), *M. manitobensis* (Whiteaves), and *Maclurites crassus* (Ulrich and Scofield)—the distinctive species of the Stewartville dolomite of the upper Mississippi Valley, which is known eastward as far as northern Michigan. This formation has been correlated with the upper Cobourg of Ontario.[113] Thus, in its

[111] G. S. Hume: *The Paleozoic outlier of Lake Timiskaming, Ontario and Quebec*, Geol. Surv. Canada, Mem. 145 (1925).

[112] G. S. Hume: *Stratigraphy and geologic relations of the Paleozoic outlier of Lake Timiskaming*, Am. Jour. Sci., 4th ser., vol. 50 (1920) p. 301.

[113] G. Marshall Kay: *Ordovician Stewartville-Dubuque problems*, Jour. Geol., vol. 43 (1935) p. 577-580.

upper part, the Liskeard formation contains the boreal fauna of the Cobourg. Presumably, most of the formation is of pre-Cobourg age, but the fauna in the beds underlying the *Maclurites* zone is meagre and not distinctive; faunal lists suggest the presence of beds of Hull age.

Utica shale.—The Utica shale (Utica, New York) was a name applied by Vanuxem [114] to the black shale of the upper Mohawk Valley. Ruedemann recognized that the black shales were of several ages, and restricted the name Utica shale to the beds overlying the Canajoharie shale.[115]

The nomenclature of the Utica shales is complex and confusing. At the type locality the Utica is probably wholly Upper Utica, but, in sections a few miles east of the city, the formation is separable into three faunal divisions. The lower two are probably of Cobourg age, but the upper seems equivalent to the Deer River and Atwater Creek shales of northwestern New York, and to the Collingwood and Gloucester formations of Ontario. Thus, a single member of the Utica formation, when traced laterally, becomes equivalent to two formations. In spite of the anomalies with respect to the standing given to these several subdivisions, it seems least confusing to consider the zones of the Utica as members of the Utica formation.

Nowadaga member of the Utica formation.—The Nowadaga shale (Nowadaga Creek, Herkimer County, New York) has been defined as the "lower Utica or zone of *Climacograptus typicalis*" [116] (Hall), and includes the "black, hard, somewhat calcareous mud shale of typical Utica appearance that follows directly above the Canajoharie" on Nowadaga Creek, through a thickness of 200 feet.[117] The member has been recognized only in sections in the upper Mohawk Valley, and its maximum thickness seems about 500 feet in the Otsquago Creek section near Fort Plain.

In addition to *Climacograptus typicalis* (Hall) and *Glossograptus approximatus* Ruedemann, which have been listed as the typical fossils, the member commonly contains *Lasiograptus eucharis* (Hall), *Leptobolus insignis* Hall, *Geisonoceras tenuistriatum* (Hall), and *Triarthrus eatoni* (Hall), all of which range beyond the limits of the member.

The member is classified as Lower Cobourg (Hallowell) and the succeeding Middle Utica (Loyal Creek) as Upper Cobourg (Hillier), although their contact may not be synchronous with the contact of the Cobourg members. That the two are of Cobourg age is evidenced by the fact that

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[114] Lardner Vanuxem: *Geology of New York. Part III, comprising the survey of the third geological district* (1842) p. 56. Albany.

[115] Rudolf Ruedemann: *Lower Siluric shales of the Mohawk Valley*, N. Y. State Mus., Bull. 162 (1912) p. 28.

[116] Rudolf Ruedemann and G. H. Chadwick: *Ordovician black shales of New York*, Science, vol. 81 (1935) p. 400.

[117] Rudolf Ruedemann: *The Utica and Lorraine formations of New York: Part I, Stratigraphy*, N. Y. State Mus., Bull. 258 (1925) p. 29-30.

they overlie the Sherman Fall limestone, and they underlie the Upper Utica (Holland Patent), which in its type locality overlies the Lower Cobourg, but in its northwestern extension lies on the Upper Cobourg. The dearth of exposures along lower West Canada Creek has prevented the determination of the exact nature of the disappearance of each facies. It is believed, however, that the Lower and Middle Utica were deposited in a sea separated from the Cobourg, inasmuch as the Cobourg is quite pure limestone in its southeasternmost exposures.

Loyal Creek member of the Utica formation.—The Loyal Creek (westernmost Montgomery County, New York) member has been defined as the "middle Utica or zone of *Dicranograptus nicholsoni*" Hopkinson [118]; it is a black, laminated shale, which extends along Nowadaga Creek "to just below Newville mill, or through about 170 feet." [119] The member is limited, as is the lower Utica, to the upper Mohawk Valley, and has a thickness of about 130 feet on Loyal Creek, near Fort Plain.

In addition to *Dicranograptus nicholsoni*, which is not listed from the Lower Utica, the member contains most of the species that are found in the underlying beds.

The Upper Utica, or Holland Patent member of the Utica formation, being of Collingwood-Gloucester age, its description is deferred to a subsequent page.

LATE TRENTON SHALE FORMATIONS

Collingwood shale.—The Collingwood shale (Collingwood, Ontario) consists of "alternating beds of limestone and shale, but its characteristic fossil, *Ogygites canadensis* [= *O. latimarginatus* (Hall)], is so abundant, that the dividing line is easily recognized." [120] When it was found that *Ogygites* is present in underlying limestones, these beds were referred to as "Lower Collingwood" [121]; later work in other areas has revealed that this form occurs sporadically at lower horizons, and that "the genus *Triarthrus* is a much more satisfactory marker of the base of the Collingwood in Ontario." [122] The "Lower Collingwood" is now included within the Cobourg formation.

In its type section, the Collingwood is overlain by the Blue Mountain formation, "blue shale, sparingly fossiliferous, and with a fauna similar

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[118] Rudolf Ruedemann and G. H. Chadwick: *op. cit.*, p. 400.

[119] Rudolf Ruedemann: *op. cit.*, p. 30.

[120] P. E. Raymond: *Trenton group in Ontario and Quebec*, Geol. Surv. Canada, Summ. Rept. for 1912 (1914) p. 349.

[121] W. A. Parks: *Faunas and stratigraphy of the Ordovician black shales and related rocks in southern Ontario*, Royal Soc. Canada, Tr., vol. 22, sec. 4 (1928) p. 46.

G. Marshall Kay: *Ordovician Trenton group in northwestern New York: stratigraphy of the lower and upper limestone formations*, Am. Jour. Sci., 5th ser., vol. 26 (1933) p. 6-7.

[122] J. C. Sproule: *A study of the Cobourg formation*, Univ. Toronto thesis (1934).

in some respects but strikingly different in others"[123]; the beds lack *Ogygites*, and are believed to be of Gloucester age. The Collingwood formation has been described as 26 feet thick in the type section.

DISTRIBUTION: The Collingwood formation is rarely exposed in central and southeastern Ontario because of its non-resistant character. It is believed to have a thickness of about 50 feet in this region, and to persist from Collingwood to the shore of Lake Ontario, near Bowmanville. In Jefferson County, northwestern New York, there are many exposures of the contact of the Deer River black shale on the Upper Cobourg limestone along Sandy Creek; the former is considered to be of Collingwood age. Exposures are so few west of the Black River valley in Lewis and northern Oneida County as to preclude the study of the base of the shales in natural exposures. In Oneida County, the Holland Patent shale, the upper member of the Utica formation, is, in its lower part, of Collingwood age (Pl. 4).

Westward from Collingwood, *Ogygites*-bearing black shales have been found on the north side of Manitoulin, back of Little Current, and shales of a more calcareous character have been found in northern Michigan.[124]

FAUNA: In addition to the trilobite *Ogygites latimarginatus* (Hall), known also from the upper Cobourg ("Lower Collingwood" of Parks), the formation contains *Triarthrus eatoni* (Hall), *Dalmanella emacerata* (Hall), *Ozoplecia calhouni* Wilson, *Glossograptus quadrimucronatus* (Hall), and *Climacograptus* sp. cf. *C. typicalis* (Hall); the fauna has been listed by Parks.[125] Some of the species are shown on Plate 10.

Deer River shale.—The Deer River shale (Deer River, northern Lewis County, New York) was defined by Ruedemann[126] as constituting the "zone of *Climacograptus typicalis posterus*" Ruedemann, the black shale lying disconformably on the upper Cobourg and below the more arenaceous Atwater Creek shale, into which it grades. The formation is about 70 feet thick in the type section.

The formation is exposed in contact with the Cobourg at many localities along Sandy Creek, in southern Jefferson County. Continuous exposure to the base of the beds is not seen southeast of the type locality, but higher beds are exposed in a number of the steep walled "gulfs" in Lewis County. In Oneida County, the shales evidently constitute the lower part of the Upper Utica or Holland Patent formation.

FAUNA: In addition to graptolites, of which the zone species is most abundant, the formation contains a number of ubiquitous Utica species, such as *Leptobolus insignis* (Hall), *Geisonoceras tenuistriatum* (Hall), and *Triarthrus eatoni* (Hall) (Pl. 10).

[123] W. A. Parks: *Faunas and stratigraphy of the Ordovician black shales and related rocks in southern Ontario*, Royal Soc. Canada, Tr., vol. 22, sec. 4 (1928) p. 53.

[124] A. F. Foerste: *Geology of the Clay Cliffs, Cape Smyth, Manitoulin Island*, Inter. Geol. Congr. XII, Canada, Guide Book no. 5 (1913) p. 78.

Rudolf Ruedemann and G. M. Ehlers: *Occurrence of the Collingwood formation in northern Michigan*, Mich. Univ. Mus. Geol., Contrib., vol. 2, no. 2 (1924) p. 13-18.

[125] W. A. Parks: *Faunas and stratigraphy of the Ordovician black shales and related rocks in southern Ontario*, Royal Soc. Canada, Tr., vol. 22, sec. 4 (1928) p. 41-43, 50-53.

[126] Rudolf Ruedemann: *Utica and Lorraine formations in New York*, N. Y. State Mus., Bull. 258 (1925) p. 52.

Ruedemann considered the beds to be of Gloucester age, but more recent studies indicate that all the listed species are known from the Collingwood shales of Ontario.[127]

Gloucester shale.—The Gloucester shale (Gloucester Township, Carleton County, Ontario, at Ottawa) is a name that was substituted for "Ontario Utica", the term previously applied to the black shale overlying the Collingwood shale.[128] The formation is discontinuously exposed in the type area, but overlies the Collingwood shale of similar lithology, and underlies arenaceous shales of lower Eden age.[129] The Gloucester is distinguished faunally by the presence of *Triarthrus spinosus* Billings. The typical Gloucester shale is gray-black, thinly laminated shale, passing upward into bluish shale; the thickness is about 50 feet.

The formation crops out in separated areas in the Ottawa district and eastward to Montreal and Quebec. In southern Ontario, it extends near Lake Ontario from Bowmanville to Whitby, and then strikes northwestward to west of Collingwood on Georgian Bay, where it is believed to form the Blue Mountain formation. The beds are very rarely exposed, and the thickness in southern Ontario is believed to be similar to that in the type section. East of Lake Ontario, the Gloucester fauna is recognizable in the Atwater Creek shale, and in the upper part of the Holland Patent formation, or Upper Utica, near Utica (Pl. 4).

FAUNA: In addition to the guide trilobite, *Triarthrus spinosus* Billings (Pl. 10), the formation contains[130] several ubiquitous Utica species, including *Triarthrus eatoni* (Hall), and such graptolites as *Leptograptus flaccidus* (Hall) and *Glossograptus quadrimucronatus* (Hall).

Blue Mountain shale.—The Blue Mountain formation (Blue Mountain, west of Collingwood, Ontario) is composed of blue, soft, sparingly fossiliferous shales overlying the Collingwood shale and underlying the Eden Dundas formation in the type section, where it is 200 feet thick;[131] the upper contact is gradational, the highest occurrence of *Triarthrus* being considered as the top of the formation. The Blue Mountain is limited in exposure to the type area, the Gloucester formation being more typically developed farther southeast, near Toronto.

The formation contains some of the typical Gloucester species, such as *Leptograptus flaccidus*, and *Glossograptus quadrimucronatus; Triarthrus spinosus rougensis* Parks, which is found in the upper typical Gloucester, is also present. The presence of *Cryptolithus bellulus* (Ulrich), an Eden species, evidences its transitional faunal aspect.

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[127] J. C. Sproule: *A study of the Cobourg formation*, Univ. Toronto thesis (1924).

[128] P. E. Raymond: *Expedition to the Baltic provinces*, Harvard Coll., Mus. Comp. Zool., Bull. 56 (1916) p. 255.

[129] A. F. Foerste: *Upper Ordovician formations in Ontario and Quebec*, Geol. Surv. Canada, Mem. 83 (1916) p. 62.

[130] W. A. Parks: *Faunas and stratigraphy of the Ordovician black shales and related rocks in southern Ontario*, Royal Soc. Canada, Tr., vol. 22, sec. 4 (1928) p. 44.

[131] *Op. cit.*, p. 53.

Atwater Creek shale.—The Atwater Creek shale (Atwater Creek, west of Martinsburg, Lewis County, New York) is the more arenaceous transitional facies between the black Deer River shale and the sandy Lorraine shale of northwestern New York.[132] In the type section, the thickness is about 70 feet, the limits being somewhat arbitrary. The formation has been recognized in a number of sections in northwestern New York, and equivalent beds seem to constitute the upper part of the Holland Patent formation, or Upper Utica, in Oneida County, where they similarly pass upward into the Eden Frankfort shale.

FAUNA: The Atwater Creek contains as the most characteristic fossils, *Climacograptus posterus* Ruedemann and *Glossograptus approximatus* Ruedemann, together with long ranging Utica forms. *Glossograptus quadrimucronatus* (Hall), typical of the Gloucester, is also represented. Ruedemann considered the Atwater Creek to be lowermost Eden; the beds are certainly transitional in fauna, and are rather arbitrarily classified with the Gloucester because the fauna seems homotaxial.

Holland Patent formation; Holland Patent member of the Utica formation.—The Holland Patent shale (Holland Patent, Oneida County, New York) is the "upper Utica, or zone of *Climacograptus pygmeus*" [133] and *Glossograptus quadrimucronatus timidus* of Ruedemann, consisting of about 200 feet of black shales grading upward into the arenaceous Frankfort shale, and lying disconformably on the lower Cobourg (Hallowell) limestone. The Holland Patent in this area is similar in stratigraphic position and relations to the combined Deer River and Atwater Creek formations of northwestern New York. In the Mohawk Valley, the same zone constitutes a similar thickness of beds along Nowadaga Creek above Newville, but lies on the Middle Utica (Loyal Creek).

FAUNA: In addition to the guide fossils, the typical Holland Patent contains *Corynoides ultimus* Ruedemann, *Climacograptus typicalis* (Hall), and species of long range within the Utica; a fauna of more than 70 species has been listed from the type locality. Among them, *Leptograptus flaccidus* (Hall), *Glossograptus quadrimucronatus* (Hall), and *Triarthrus spinosus* Billings are indicative of a Gloucester age for at least a part of the formation. Ruedemann believed the lower part to be of Collingwood age on the evidence of other included graptolites, although *Ogygites* has not been found.

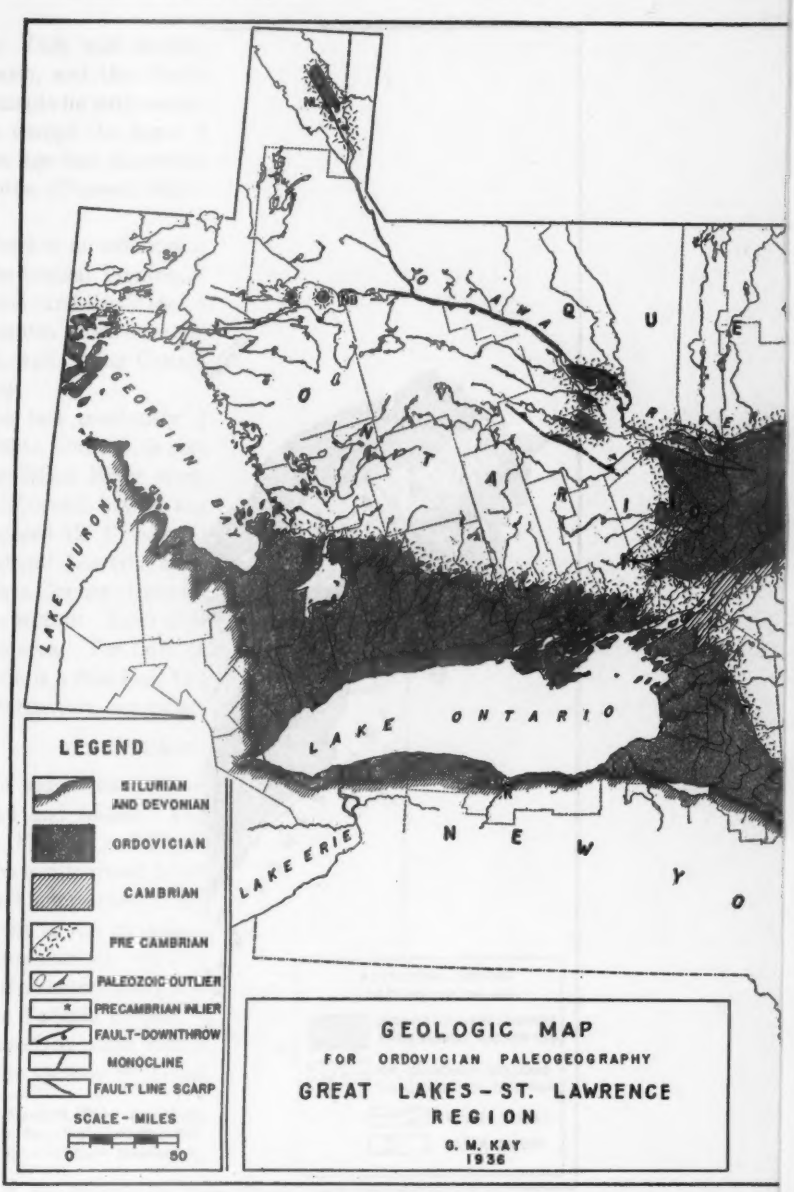
SUCCEEDING FORMATIONS

Throughout the New York-Ontario region, where sediments of post-Trenton age are preserved, they are of lower Cincinnatian Eden age and of clastic character. They comprise the lower Lorraine sandy shales in

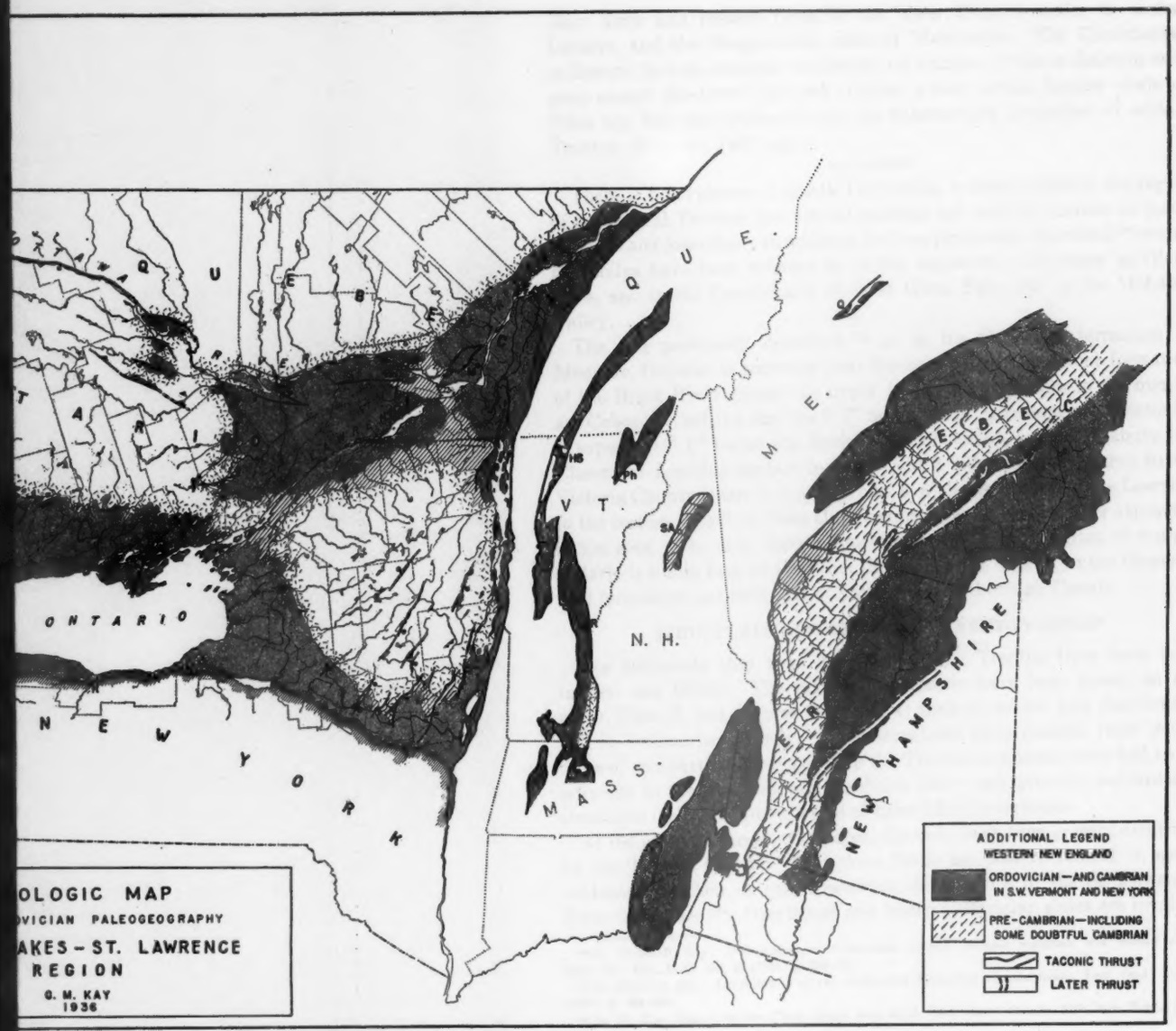
[132] Rudolf Ruedemann: *Utica and Lorraine formations in New York*, N. Y. State Mus., Bull. 258 (1925) p. 60.

[133] Rudolf Ruedemann and G. H. Chadwick: *Ordovician black shales of New York*, Science, n. s., vol. 81 (1935) p. 400.

Rudolf Ruedemann: *Utica and Lorraine formations in New York*, N. Y. State Mus., Bull. 258 (1925) p. 41.



GEOLOGICAL MAP OF THE GREAT LAKES-ST



ICAL MAP OF THE GREAT LAKES-ST. LAWRENCE REGION, PALINSPASTIC FOR THE ORDOVICIAN

New York and eastern Ontario, the lower Dundas shales in central Ontario, and the Sheguiandah shale of Manitoulin. The Cincinnatian sediments lie with essential conformity on youngest Trenton shales in each area except the lower Mohawk Valley, where Indian Ladder shale of Eden age lies disconformably on the Schenectady formation of middle Trenton (Sherman Fall) age.

VOLCANISM

There is no evidence of middle Ordovician volcanoes within the region of the typical Trenton, but altered volcanic ash beds are known at many horizons and localities. In addition to those previously described,[134] metabentonites have been referred to in the Amsterdam limestone at Glens Falls, and in the Canajoharie shale at Glens Falls and in the Mohawk Valley.

The bed previously described[135] as in the Coboconk formation at Medonte, Ontario, is correctly near the base of the Chaumont formation of the Black River group; the upper 12 feet of limestones in the quarry are Coboconk, but the clay lies 8′ 7″ below them. The same metabentonite is exposed 12′ 1″ below the Rockland (Coboconk), and 2′ 4″ above the Chaumont-Lowville contact in a road cut 2 miles south of Burnt River, Victoria County; there is a similar clay 9′ 6″ below the top of the Lowville in the section. Each of these clays has been recognized in other exposures in the area. The only observed metabentonite in the Trenton of central Ontario is a thin bed, 16 feet from the floor of the quarry, in the Sherman Fall formation, one mile east of Lakefield, Peterborough County.

STRUCTURES AFFECTING THE TRENTON GROUP

The sediments that were deposited during Trenton time have been faulted and folded. The principal structures have been shown on the maps, Plate 5, and Figures 2, 3, and 4; their character and distribution will be summarized briefly. Other structures have resulted from initial dip and compaction in areas where the Trenton sediments were laid on or adjacent to the irregular pre-Cambrian floor; and primary sedimentary structures include ripple-marks and subsolifluction breccias.

At the eastern margin of the area, the beds have been greatly disturbed by the Taconic thrusts. That these faults are post-Richmond in age is evidenced by their cutting Queenston shales south of the St. Lawrence River in Quebec.[136] Overthrust and folded Ordovician slates are overlain

[134] G. Marshall Kay: *Distribution of Ordovician altered volcanic materials and related clays*, Geol. Soc. Am., Bull., vol. 46 (1935) p. 226-231.

[135] G. Marshall Kay: *Stratigraphy of the Ordovician Hounsfield metabentonite*, Jour. Geol., vol. 39 (1931) p. 367-368.

[136] R. W. Ells: *Report on the Three Rivers map sheet*, Geol. Surv. Canada, 11th Ann. Rept., pt. J (1901) map.

unconformably by late Silurian Manlius limestone at Becraft Mountain, near Hudson, New York;[137] the contact is clearly shown in a cut on the Albany Post Road, southwest of the mountain. Farther southeast, folded beds west of the principal thrusts are overlain unconformably by early Silurian conglomerates. Sediments deformed in the Taconic disturbance are overlain by middle Silurian Lockport beds east of the Green Mountains.[138] Thus, the Taconic thrusts seem of post-Richmond, and pre-middle Silurian age.

On the southeast side of the Adirondack Mountains is a set of northeastwardly-trending, high-angle faults, downthrown as much as 2000 feet on a single fault plane.[139] The faults cut beds as young as the latest Trenton. Joints parallel to these faults have basic dikes whose helium ratio indicates their late Ordovician or Silurian age;[140] some of the joints may be pre-Cambrian.[141] Several of the faults have throws of several hundred to more than 1000 feet at the Mohawk River; their southward extension has not been mapped in the drift-mantled area of difficultly separable shales. The absence of similar faults in the upper Silurian limestones of the adjacent Helderberg escarpment supports the belief that they are of pre-late Silurian age. Although their age limits are defined similarly to those of the Taconic thrusts, they need not be exactly synchronous.

Parallel faults on the northwest side of the Adirondack axis are downthrown on their western sides. They are of smaller displacement, and the fault in this belt at Prospect, New York, is a thrust.[142] The similarity in position of the axis separating the opposing faults to that of the earlier Adirondack Arch that affected Trenton sedimentation suggests that they form a part of a structural development that commenced in the earlier Ordovician.

In the Ottawa district, there are faults cutting beds as young as the Queenston shale.[143] The upper Ottawa Valley has the structure of a graben, with faults of the order of 1000 to 1500 feet on either side. In the vicinity of Lake Timiskaming, similar faults cut Silurian Lockport

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[137] Charles Schuchert and C. R. Longwell: *Paleozoic deformations of the Hudson Valley region*, Am. Jour Sci., 5th ser., vol. 23 (1932) p. 305-321.

[138] T. H. Clark: *Structure and stratigraphy of southern Quebec*, Geol. Soc. Am., Bull., vol. 45 (1934) p. 18-19; *Silurian rocks of Lake Memphremagog, Quebec*, Canadian Field-Nat., vol. 50 (1936) p. 31.

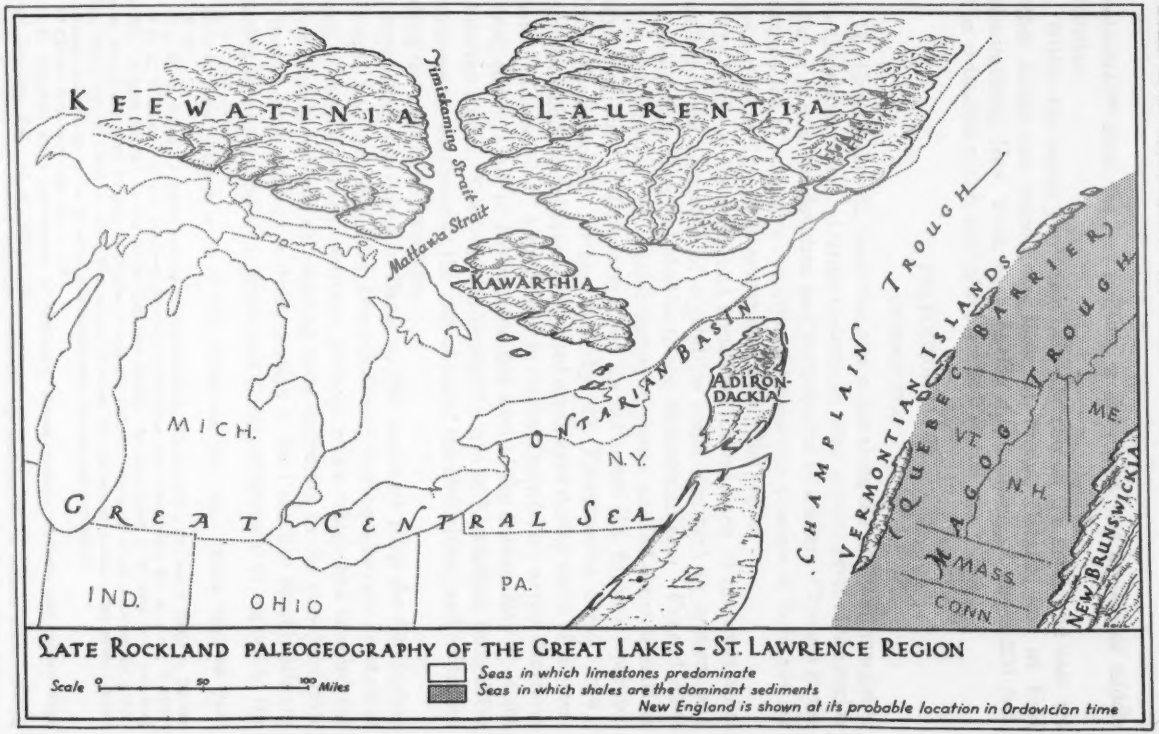
[139] W. J. Miller: *Geology of the Lake Pleasant quadrangle*, N. Y. State Mus., Bull. 182 (1916) p. 45-48.

[140] W. D. Urry: *Ages by the helium method*, Geol. Soc. Am., Bull., vol. 47 (1936) p. 1218.

[141] Robert Balk: *Geology of the Newcomb quadrangle*, N. Y. State Mus., Bull. 290 (1932) p. 68.

[142] W. J. Miller: *Geology of the Remsen quadrangle*, N. Y. State Mus., Bull. 126 (1909) p. 23-27.

[143] R. W. Ells: *Report on the geology and natural resources of the area included in the map of the city of Ottawa and vicinity*, Geol. Surv. Canada, 12th Ann. Rept., pt. G (1901).



PALEOGEOGRAPHY OF EARLIER TRENTON (LATE ROCKLAND) TIME

dolomite;[144] thus, the last faulting in the region was as late as middle Silurian.

Within the region bordering Lake Ontario on the north and east are other faults and monoclines, those at Picton, Ontario, and at East Martinsburg, New York, each having displacement of about 200 feet. The sediments which they affect are of Trenton age.

PALEOGEOGRAPHY

INTRODUCTION

The Great Lakes-St. Lawrence region lies along the southeast margin of the Canadian Shield. During Ordovician time, several parts of the region differed in relative elevation and in structural character. Changes in the distribution of seas were conditioned by eustatic changes in level, and by epeirogenic and orogenic movements within the region.

The lands on the north and northwest formed parts of the continental nucleus, were composed of crystalline rocks, resistant to erosion, and furnished only marginal clastics to the Mohawkian seas. Coastal relief of a few hundred feet caused embayed shores and off-shore islands in advancing seas.[145] *Laurentia,*[146] on the northeast (Pl. 6), was separated from *Keewatinia,*[147] farther west, by the *Timiskaming Strait* (new), through which boreal faunas migrated southward during times of submergence. *Kawarthia,*[148] a small land in central Ontario, lay across *Mattawa Strait* (new), south of Keewatinia, and west of the *Ottawa Bay*[149] of the Ontarian Basin. The *Ontarian Basin,*[150] south of Kawarthia, formed the northeastern extension of the central sea of the Ordovician, and continued along the margin of Laurentia.

Separating the Ontarian Basin on the southeast from the Champlain Trough, was the small land *Adirondackia,*[151] having a central crystalline area of relatively high, resistant, plutonic rocks, which had invaded the more readily reduced surrounding meta-sediments in the pre-Cambrian. Although essentially an outlying portion of the Canadian Shield, Adirondackia was uparched as orogenic movements progressed in regions to the

[144] G. S. Hume: *Paleozoic outlier of Lake Timiskaming,* Geol. Surv. Canada, Mem. 145 (1925) p. 47-52.

[145] A. W. G. Wilson: *Physical geology of central Ontario,* Canad. Inst., Tr., vol. 7 (1901) p. 139-186.

[146] H. S. Williams: *On the southern Devonian formations,* Am. Jour. Sci., 4th ser., vol. 3 (1897) p. 394. A term applied to the whole Canadian Shield. In this paper it is used in a restricted sense, and is essentially *Ungava* of Charles Schuchert: *Paleogeography of North America,* Geol. Soc. Am., Bull., vol. 20 (1910) p. 473. This article discusses the history of names. The present paper conforms to the terms as far as seems concordant with changing interpretations.

[147] Charles Schuchert: *op. cit.,* p. 473.

[148] G. Marshall Kay: *Distribution of Ordovician altered volcanic materials and related clays,* Geol. Soc. Am., Bull., vol. 46 (1935) p. 241.

[149] E. O. Ulrich and Charles Schuchert: *Paleozoic seas and barriers in eastern North America,* N. Y. State Mus., Bull. 52 (1902) p. 639; they considered it a bay of the St. Lawrence trough.

[150] New in this sense—not the Ontario Basin in Charles Schuchert: *op. cit.,* p. 455.

[151] *Op. cit.,* p. 473.

east. This *Adirondack Arch*[152] continued southward as an orogenic foreland fold in the earlier Paleozoic sediments. The *Champlain Trough*[153] extended northeastward, joining the Ontarian Basin to form the *St. Lawrence Trough*,[154] which continued along the southeastern side of Laurentia.

These last named troughs were, in the earlier Ordovician, separated by the *Quebec Barrier*[155] from the *Magog Trough*[156] farther east. Whether this "barrier" was a linear land, a submerged arch, or the margin of the continental shelf, is incidental. The significant things are that it separates calcareous sediments on the west from non-calcareous on the east, and the zone seems to have been one in which structural movements were concentrated. The contrast of the two facies being similar to that in the middle Trenton on the flanks of the Adirondack Arch, the writer is of the opinion that the "barrier" was a structural high, resulting from folding or faulting, rather than the margin of a continental slope.[157] The "barrier" may have been transgressed by shallow seas that impeded the westward spread of the sediment-laden waters from the eastern trough; if the faunas are dependent on the facies, they have no bearing on whether or not there was a separating land.

The Quebec Barrier was disturbed within the lower Ordovician (post-*Ceratopyge* time[158]). This had been called the Green Mountains Disturbance;[159] recently, the term Vermont Disturbance was substituted. The writer proposes that this disturbance affecting the Quebec Barrier be called the *Quebec Disturbance*, that which formed the land Vermontia in Middle Trenton time, the Vermontian Disturbance, and that the geanticline formed by the Taconic disturbance at the close of the Ordovician be called Taconica. The use of similar names for the disturbances and their products should avoid confusion, which is otherwise introduced.

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[152] G. Marshall Kay: *The Ordovician Adirondack foreland fold*, Geol. Soc. Am., Pr. for 1935 (1936) p. 390.

[153] J. D. Dana: *Manual of geology*, 4th ed. (1894) p. 461, in which the Champlain Group of Emmons, 1842, was deposited. The term "Chazy basin" [E. O. Ulrich and Charles Schuchert: *op. cit.*, p. 638] is confusing because of the presence of the Chazyan series in the area.

[154] Essentially the St. Lawrence channel of E. O. Ulrich and Charles Schuchert [*op. cit.*, p. 636], and of J. D. Dana [*Manual of geology*, 2nd ed. (1874) p. 146].

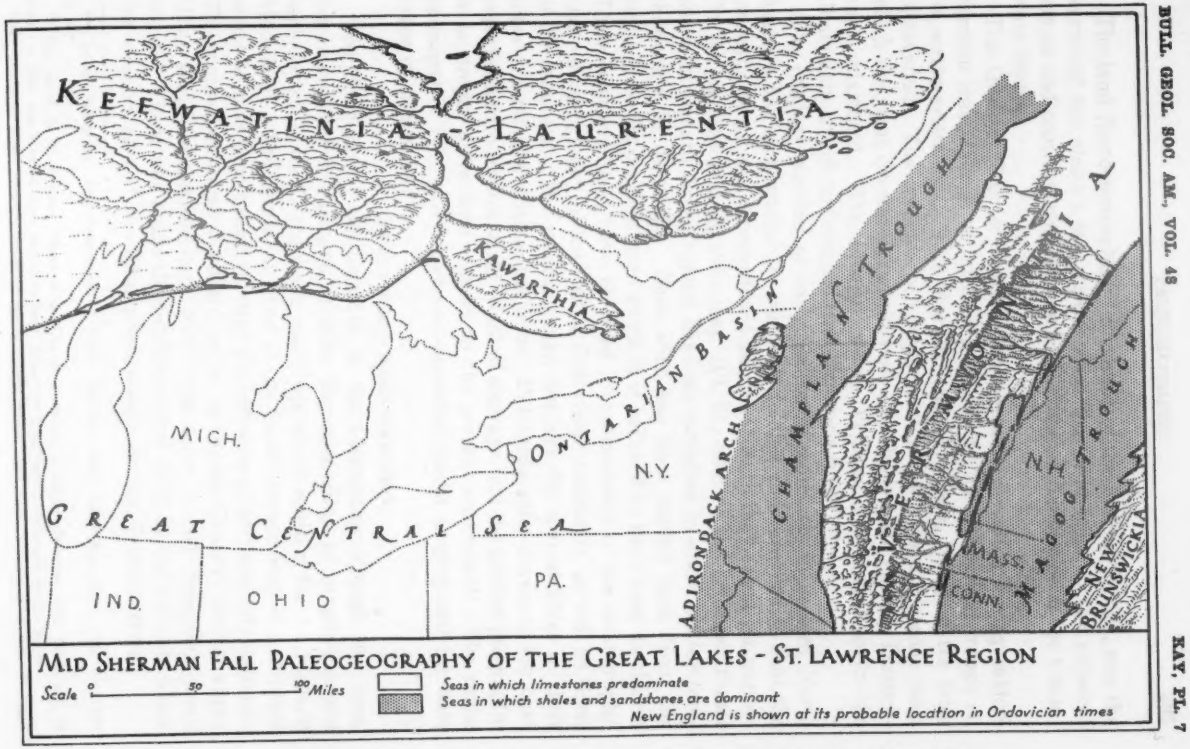
[155] E. O. Ulrich and Charles Schuchert: *op. cit.*, p. 639.

[156] New—an abbreviation of Memphremagog Trough, in which the Memphremagog series [C. H. Richardson: *Geology of Newport, Troy and Coventry*, Vermont St. Geol., 6th rept. (1908) p. 276], the Ordovician of eastern Vermont, was deposited. This is essentially the Levis channel of Ulrich and Schuchert, a term that had been applied to a formation within the trough; Bain [*The northern area of the Connecticut Valley Triassic*, Am. Jour. Sci., 5th ser., vol. 23 (1932) p. 77, fig. 8] has used "Memphremagog Embayment" in a somewhat similar sense, but with different interpretation of the paleogeography.

[157] E. B. Bailey, L. W. Collet, and R. M. Field: *Paleozoic submarine landslips near Quebec City*, Jour. Geol., vol. 36 (1928) p. 609-611.

[158] Percy Raymond, *by* Charles Schuchert: personal communication.

[159] E. O. Ulrich and Charles Schuchert: *op. cit.*, p. 639.



PALEOGEOGRAPHY OF MEDIAL TRENTON (LATE SHERMAN FALL) TIME

The land *Newbrunswickia*,[160] southeast of the Magog Trough, was the source of the clastics that characterize the Ordovician in the adjacent trough and contrast with the earlier Ordovician limestones in the Champlain trough.

The Quebec "Barrier" rose to considerable elevation during middle Trenton time, thereafter furnishing clastics to the Champlain trough on its northwestern side. This was the land *Vermontia* (new) of the later Ordovician. The orogenic belt seems also to have been the zone from which the great overthrusts of the post-late Ordovician Taconic Disturbance originated. The orogeny drove Vermontia westward over the Champlain trough to form the land *Taconica* (new).[161]

The original position of early Paleozoic sediments in eastern North America has been altered by this later folding and thrusting so that the present map gives a foreshortened base relative to the ancient geography. On the paleogeographic base map (Pl. 5), each of the principal thrust sheets in western New England has been stretched to overcome the foreshortening in its width. Each slice has been moved back from the foreland to the position from which it is believed to have been displaced. These interpretations have involved a consideration of the stratigraphy and paleogeography of the earlier Ordovician sediments, as well as those of Trenton age. The resulting map displays the several slices in their conceived relative original positions. Paleogeography drawn on the base is realistic with respect to the width of seaways, and the ancient geography is in proper place with respect to the present outcrops.[162] The name *palinspastic* (Gr. παλι[ν]σπαστικ—stretched back) is proposed for base maps of this character.

CURRENTS AND WIND DIRECTION

The direction of the currents in the Champlain Trough has been determined by Ruedemann[163] from the orientation of graptolites and cephalopods in the Canajoharie and Utica shales south of the Adirondack Mountains. The persistent trend of the fossils toward west of southwest seems to have been gained through the influence of northeasterly currents. The control continued westward as far as Oneida County; similar upper Utica shales of northwestern New York seem to lack persistent fossil trends. There was evidently southwestward drift in the currents along the western side of the Champlain trough during Trenton time.

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[160] Charles Schuchert: *Paleogeography of North America*, Geol. Soc. Am., Bull., vol. 20 (1910) p. 467.

[161] Taconia of A. W. Grabau [*Physical and faunal evolution of North America*, Jour. Geol., vol. 17 (1909) p. 221] was a much more extensive land, based on a different conception of the history.

[162] G. Marshall Kay: *Taconic thrusting and paleogeographic base maps*, *Science*, n. s., vol. 82 (1935) p. 616-617.

[163] Rudolf Ruedemann: *Evidence of current action in the Ordovician of New York*, Am. Geol., vol. 19 (1897) p. 367-391; *Additional note on the oceanic current in the Utica epoch*, Am. Geol., vol. 21 (1898) p. 75-81.

The significance of the orientation in direction of para-ripple-marks in Trenton limestones in northwestern New York and along the Mohawk Valley is not as conclusively known. The strikes of about 150 ripple-marks have been measured in these areas. Although their trend is predominantly northwestward, successive ripples are occasionally at high angles to each other, and there is greater consistency in direction in some horizons than in others. In northwestern New York, 35 of 52 measured in the Hull formation were in a sextant centered N60°W, but only 22 of 41 in the Sherman Fall in a sextant trending N10°W. The ripple-marks are normally in coarse-textured limestones; occasionally they affect conglomerate beds having flat, rounded limestone pebbles up to 2 or 3 inches in diameter. They have wave-lengths of 25 to 40 inches, and amplitudes about a tenth as great; they are symmetrical and anastamosing. The troughs are filled with dark shale. Fossils on their crests are often well-preserved, and seem unoriented. Although para-ripples are abundant in some sections, they are quite lacking in others, as at Trenton Falls.

Similar ripples in Quebec have been attributed to "storm waves of unusual size whose oscillations penetrated to a depth not affected by ordinary waves."[164] It has been suggested that those in other regions were produced by tidal currents, and by tidal currents strengthened by drift during periods of storms;[165] the ripples were believed to be at high angles to the shores. The essential symmetry of the Trenton para-ripples, the contrasting orientation of adjacent ripples, and consideration of probable shore lines lead the writer to believe that the trend of the ripples has been controlled by storm waves in the open sea. That they were formed in rather shallow water is suggested by their preservation in conglomerate beds, and their abundance in the Mohawk Valley immediately above unconformities. The range in abundance in different sections probably reflects control by depth, and limitations in fetch of the dominant winds.

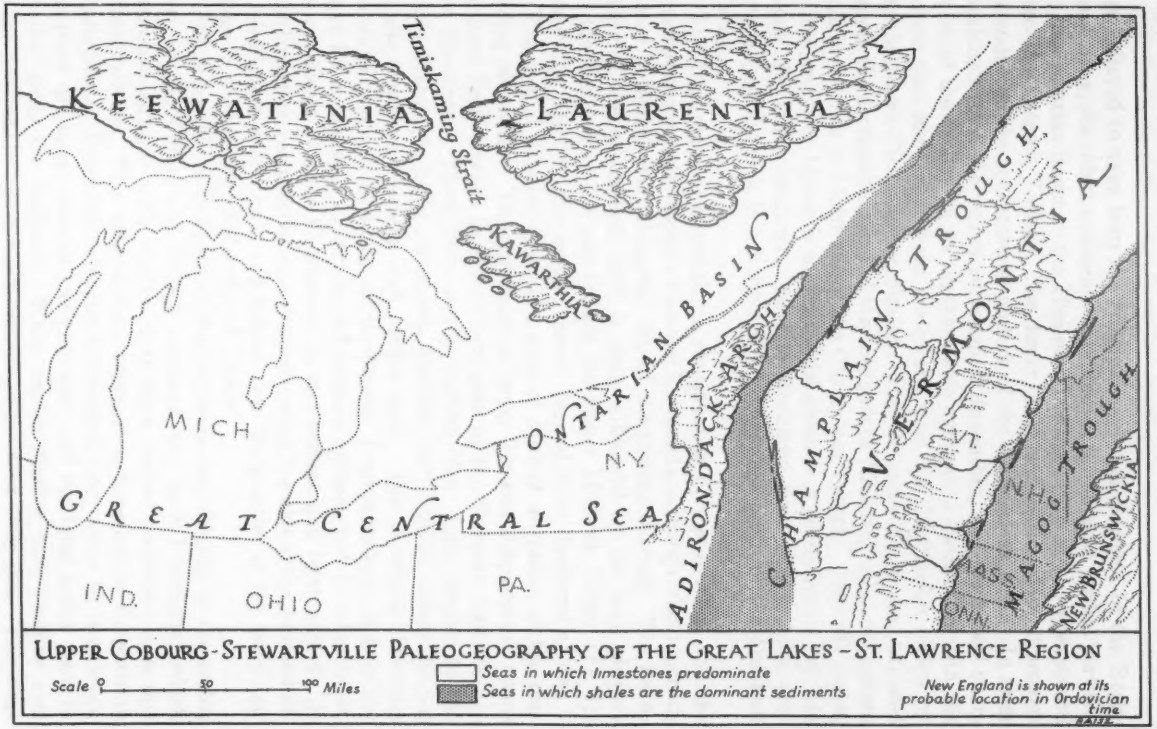
It is thought that during Trenton time, storm winds in northwestern New York came principally from either the northeastward or southwestward, across the dominant trend of the para-ripples. But other storms came from various directions.

TRENTON HISTORY

The early Trenton was fundamentally a time of advancing seas that progressively submerged the margins of the lands. Eustatic movements

[164] E. M. Kindle: *A comparison of the Cambrian and Ordovician ripple-marks found at Ottawa, Canada*, Jour. Geol., vol. 22 (1914) p. 713.

[165] W. H. Bucher: *On ripples and related sedimentary surface forms and their paleogeographic interpretation*, Am. Jour. Sci., 4th ser., vol. 47 (1919) p. 258-268.



PALEOGEOGRAPHY OF UPPER COBOURG-STEWARTVILLE TIME

are believed to have been the principal causes of change. In the Rockland stage, the oldest sediments were limited to the more medial portions of the Ontarian Basin, in the Thousand Islands region and northwestward into the Ottawa Valley. The lower Rockland Amsterdam limestone extended on the southeastern portion of the Adirondack Arch. In later Rockland time, the waters surrounded Kawarthia, and the boreal character of the faunas on its northern side evidence a connection with the Arctic that must have been northward from the Manitoulin region by the Mattawa-Timiskaming Straits. The Ontarian Basin sea extended across the northeastern end of the Adirondack Arch and along its eastern side in the Isle la Motte sea of the Champlain Trough. That the region of the arch was higher is shown by the absence of sediments of this age along the lower Mohawk. In late Rockland time (Pl. 6), the seas overlapped the arch in a narrow strait somewhat north of the Mohawk Valley.

The Hull stage is essentially a continuation of this overlap, and the formation is well developed all around Kawarthia, although island monadnocks projected even along the line of the present outcrop. The instability of the Adirondack Arch is again evidenced by the local absence of the Hull where the axis crosses the Upper Mohawk Valley (Pl. 2); generally, however, the seas advanced beyond their Rockland shores.

The medial Trenton marked a time of distinct alteration of the preceding conditions. The maximum of lower Trenton submergence seems to have been reached in the earliest part of the Sherman Fall stage—the Shoreham. These beds are, in eastern New York, similar to the lower Trenton in being limestones, but they are faunally closely related to the overlying Sherman Fall farther west. The Shoreham limestone seems to have extended over all the present Trenton outcrop; it may not have been deposited in certain Adirondack outliers, but in other cases, as northwest of Lake Champlain, it was present and later eroded. It overlapped on early Ordovician dolomite, along the axis of the Adirondack Arch along the Mohawk, and spread over the granites of the pre-Cambrian in the vicinity of the city of Quebec.

Following this early Sherman Fall submergence, orogeny in the region east of the Champlain Trough produced the land Vermontia, which furnished streams with clastics that were carried westward into this Champlain sea. This structural movement may be called the *Vermontian Disturbance*. Synchronously, the Adirondack Arch seems to have risen, for there are conglomerates along its axis, and the later shales seem to overlap along the Mohawk. While muddy clastics were forming east of the arch, shaly limestones persisted on the west (Fig. 10). This condition was probably due to failure of marine currents to transgress the arch rather than to isolation of the waters on the west.

Late Sherman Fall seas (Pl. 7) must have quite submerged the Adirondack region. At the same time, the fluviatile plains had extended far westward from Vermontia, and marginal marine clastic deposits were laid down in the lower Mohawk region. It is possible that the submergence of the arch was the result of adjustment following the displacement

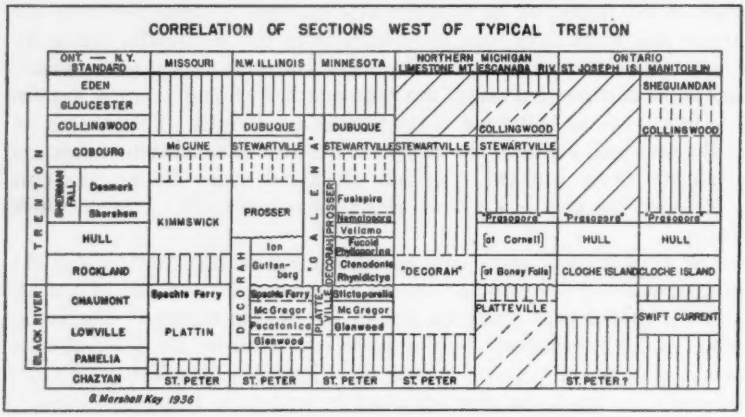


FIGURE 13.—*Correlation of Mohawkian formations west of the region of the typical Trenton*

The sections illustrate the persistent unconformity in later Sherman Fall time. Section at Limestone Mountain, Northern Michigan, after E. C. Case and W. I. Robinson: *Geology of Limestone Mountain and Sherman Hill in Houghton County, Michigan*, Mich. Geol. Biol. Surv., Publ. 18 (1915).

of the great mass of material from Vermontia into the Champlain trough (Pl. 4), for it seems significant that in the interior of the continent this is a time of emergence rather than submergence; contrast Figures 10 and 13.

Cobourg time is marked by a retreat of the sea from the Adirondack Arch into the Ontarian Basin, while clastics continued to form in the narrowed seaway between the arch and the fluviatile plains extended from Vermontia. That the arch was a land barrier is suggested by the contrasting pure limestones on the west and the fine-grained clastics on the east (Fig. 10), and by the stratigraphic evidence of the retreat of the late Cobourg into farthest northwestern New York (Pl. 4 and Pl. 8). This withdrawal is again in contrast with conditions in the continental interior, for, from Michigan westward, the Cobourg (Stewartville) sea seems to have been the most widespread of all the Trenton submergences, and may have formed the greatest submergence in geologic history. Thus, it would seem that the Adirondack Arch was rising during Cobourg time. forcing the seas to retreat. Boreal waters, carrying the *Maclurites-Receptaculites* fauna of the Stewartville, extended southward into the

Timiskaming Strait, and also entered the region of the Mississippi Valley along the west of Keewatinia.

The latest Trenton sediments in the region are uniformly fine-grained clastics. The Collingwood deposits are as extensive as the Cobourg westward, and also transgress the Adirondack Arch; the succeeding Gloucester is similarly of shale. It is believed that, with resubmergence of the Adirondack Arch following the Cobourg withdrawal, the westward spread of clastics was permitted. Earlier sediments having essentially buried the arch, the restricted Champlain Trough into which clastics from Vermontia were being carried, continued directly into the eastern margin of the Ontarian Basin.

Deposits of Trenton age younger than the Vermontian Disturbance have not been recognized in New England or southern Quebec. Cincinnatian sediments must have been laid down southeast of Vermontia in Quebec, and later Trenton deposits may be represented in the metamorphosed and unclassified clastics of central New England and southeastern Quebec.

LATER ORDOVICIAN HISTORY

The history of the Cincinnatian epoch in the region is one of the emergence of the eastern part of the area, with resultant westward marine withdrawal. Early Cincinnatian (Indian Ladder) sandy shales overlapped eastward on middle Trenton sandstones in the lower Mohawk Valley. They are the youngest Ordovician sediments in that area, being unconformably overlain by late Silurian beds. Throughout the rest of the region, clastic sediments of Eden and Maysville age succeed late Trenton shales. Marine sediments were deposited southwest of the Adirondack Mountains to the beginning of Richmond time but continued to form in the early Richmond (Waynesville) in the northern extension of the Champlain Trough in southeastern Quebec.

Marginal marine or fluviatile Queenston red shales succeed the marine Richmond in Quebec and Ontario as far westward as Georgian Bay. They seem to overlay the marine beds gradationally westward, overlying Waynesville sediments in Quebec, but succeeding younger Liberty and Whitewater shales in central Ontario.[166] This westward marine withdrawal may have resulted from epeirogenic rise of the southeastern part of the region. The influx of clastics resulting from the rejuvenation of Vermontia must have accentuated withdrawal through the forward building of graded continental plains. That the withdrawal was not due to eustatic change is suggested in the great spread of Richmond seas in the interior of the continent.

[166] A. F. Foerste: *Upper Ordovician of Ontario and Quebec*, Geol. Surv. Canada, Mem. 83 (1916) p. 162-176.

GLOSSARY OF TERMS APPLIED TO MOHAWKIAN DIVISIONS

Division	Lithology*	Type locality	Author	Year	Classification	Page
Amsterdam	ls.	Mohawk Valley	Cushing	1911	L. Rockland	259
Atwater Creek	sh.	N. W. New York	Ruedemann	1925	Gloucester	286
Black River	group	N. W. New York	Vanuxem	1842	group	244
Blue Mountain	sh.	Central Ontario	Parks	1929	Gloucester	285
Canajoharie	sh.	Mohawk Valley	Ruedemann	1912	Denmark	268
†Champlain	"group"	Lake Champlain	Emmons	1842	extensive	244
Chaumont	ls.	N. W. New York	Kay	1929	U. Black River	147
Chuctanunda	sh.	Mohawk Valley	Ruedemann and Chadwick	1935	Canajoharie	270
Cloche Island	ls.	Manitoulin	Foerste	1912	Rockland	257
Cobourg	ls.	S. E. Ontario	Raymond	1921	standard	277
Coboconk	ls.	Central Ontario	Johnston	1911	Rockland	256
Collingwood	sh.	Central Ontario	Raymond	1914	standard	283
Cumberland Head	ls., sh.	Lake Champlain	Cushing	1915	Denmark	274
Deer River	sh.	N. W. New York	Ruedemann	1925	Collingwood	284
Denmark	ls.	N. W. New York	Kay	1936	Sherman Fall	267
Depauville	ls.	N. W. New York	Emmons	1840	Black River	—
Dolgeville	sh., ls.	Mohawk Valley	Cushing	1909	Denmark	271
Fairfield	sh.	Mohawk Valley	Vanuxem	1842	Canajoharie	270
Fort Plain	sh.	Mohawk Valley	Ruedemann and Chadwick	1935	Canajoharie	271
Frankfort	sh.	Mohawk Valley	Vanuxem	1840	Cincinnatian	244
Ganservoort	sh.	Hudson Valley	Ruedemann and Chadwick	1935	Canajoharie	270
Glenburnie	sh.	S. E. Ontario	Kay	1929	Chaumont	247
Glens Falls	ls.	Hudson Valley	Ruedemann	1912	Hull and Shoreham	262
Gloucester	sh.	Ottawa Valley	Raymond	1916	standard	285
†Haileybury	ls.	Lake Timiskaming	Hume	1920	Liskeard	281
Hallowell	ls.	S. E. Ontario	Kay	1936	L. Cobourg	278
Highgate Springs	"series"	Lake Champlain	Hitchcock	1862	extensive	—
Hillier	ls.	S. E. Ontario	Kay	1936	U. Cobourg	280
Holland Patent	sh.	Mohawk Valley	Ruedemann and Chadwick	1935	Utica	286
†Hudson River	"group"	Hudson Valley	Mather	1839	extensive	247
Hull	ls.	Ottawa Valley	Raymond	1914	standard	261
Iberville	sh.	Lake Champlain	Clark	1934	Utica (?)	275
Isle la Motte	ls.	Lake Champlain	Emmons	1842	Rockland	260
†Kirkfield	ls.	Central Ontario	Johnston	1910	extensive	262
Lacolle	cgl.	Lake Champlain	Clark	1934	Sherman Fall	275
Larrabee	ls.	Lake Champlain	Kay	1936	Hull	262
Leray	ls.	N. W. New York	Ruedemann	1910	Chaumont	246
Liskeard	ls.	Lake Timiskaming	Hume	1925	Cobourg and older	281
Lowville	ls.	N. W. New York	Clarke and Schuchert	1899	M. Black River	246
Loyal Creek	sh.	Mohawk Valley	Ruedemann and Chadwick	1935	Utica	283
Minaville	sh.	Mohawk Valley	Kay	1936	Canajoharie	268
†Mohawk	ls.	Mohawk Valley	Conrad	1838	Amsterdam	242
			Hall	1842	"Mohawk group"	—
Mohawkian	series	Mohawk Valley	Clarke and Schuchert	1899	series	246
Morphy	sh.	Mohawk Valley	Ruedemann and Chadwick	1935	Canajoharie	269
Napanee	ls.	S. E. Ontario	Kay	1936	Rockland	255
Nowadaga	sh.	Mohawk Valley	Ruedemann and Chadwick	1935	Utica	282
Pamelia	ls.	N. W. New York	Cushing	1908	L. Black River	246
†Picton	ls.	S. E. Ontario	Raymond	1914	Cobourg	277

* cgl.—conglomerate; ls.—limestone; sh.—shale; ss.—sandstone.
† Abandoned term.

Division	Lithology	Type locality	Author	Year	Classification	Page
Rideau	ss.	S. E. Ontario	Ami	1902	Pamelia	—
Rockland	s.	Ottawa Valley	Raymond	1913	standard	251
Rysedorph	cgl.	Hudson Valley	Ruedemann	1901	Shoreham (?)	276
Schenectady	sh., ss.	Mohawk Valley	Ruedemann	1912	Canajoharie	273
Selby	ls.	S. E. Ontario	Kay	1936	Rockland	252
Sherman Fall	ls.	Mohawk Valley	Kay	1929	standard	263
Shoreham	ls.	Lake Champlain	Kay	1936	L. Sherman Fall	264
Snake Hill	sh.	Hudson Valley	Ruedemann	1912	Canajoharie	272
Sprakers	sh.	Mohawk Valley	Ruedemann and Chadwick	1935	Canajoharie	269
Stony Point	sh.	Lake Champlain	Ruedemann	1921	Canajoharie	275
Swift Current	ls., sh.	Manitoulin	Foerste	1912	Black River	258
Trenton	group	Mohawk Valley	Conrad	1837	group	242
Utica	sh.	Mohawk Valley	Vanuxem	1842	Cobourg to Gloucester	282
Watertown	ls.	N. W. New York	Ruedemann	1910	Chaumont	246

The Taconic disturbance followed. Great overthrusts brought sediments of the Magog Trough far westward on those of the Champlain Trough. The character of faults west of the Adirondack axis suggests that they were formed by compressive movements during the disturbance. The eastward downfaulting of the eastern side of the arch has been attributed to tensional stresses following compression.[167] The opinion that the normal faulting along Lake Champlain preceded the thrusting has been based on the absence of reported normal faulting of overthrust rocks.[168] Recent mapping in northwestern Vermont reveals northeastwardly-striking high-angle faults transecting tightly folded middle Ordovician limestones; the principal faults are downthrown on the southeast. If these belong to the Adirondack fault system, as their position and trend suggest, the Adirondack normal faulting must be later than Taconic thrusting.

Thus, it seems that the Cincinnatian uplift of Vermontia was culminated in its being overthrust westward in the Taconic Disturbance to form the new land Taconica. This was within post-Richmond (post-Queenston) and pre-middle Silurian (Lockport) time. Following this period of compression, normal faulting downdropped the eastern side of the Adirondack Arch prior to the late Silurian. The principal faulting in the Ottawa Valley region is at least in part of post-Lockport age; its synchronism with that of the Adirondack region has not been demonstrated.

CONCLUSION

The stratigraphy of the Trenton group reveals the influence of regional structural development on the distribution, lithology, and fauna of the

[167] G. R. Megathlin: *Faulting in the Mohawk Valley*, Science, n. s., vol. 82 (1935) p. 492.

[168] A. W. Quinn: *Normal faults of the Lake Champlain region*, Jour. Geol., vol. 41 (1933) p. 132-133.

sediments. In the early Trenton Rockland and Hull stages, limestone-depositing seas advanced on lands retaining characteristics inherited from the earlier Ordovician; boreal faunas invaded in the Rockland. In the middle Trenton Sherman Fall stage, the Vermontian Disturbance produced a geanticline east of the region that became an important source of detrital sediments; there was some synchronous elevation of the Adirondack Arch. Extensive seas in this stage may reflect epeirogenic depression accompanying the displacement of clastics from the east into the eastern part of the region. The Adirondack Arch influenced currents in the seas that transgressed it, limiting the westward spread of fine-grained detritals; limestones continued to form west of the arch. Faunas on the two sides reflect the differing facies. In the later Trenton Cobourg stage, the arch continued to rise, and the trough on the east was restricted by the incursion of sediments on its eastern side; boreal faunas again invaded the northern part of the region. In the latest Trenton Collingwood and Gloucester stages, shale-forming fine-grained clastics spread far westward. Latest Ordovician and early Silurian Taconic movements progressed in similar belts to those that had been disturbed in Trenton time.

Columbia University, New York, N. Y.
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EXPLANATION OF PLATES 9 and 10

PLATE 9

TYPICAL FOSSILS FROM ROCKLAND AND HULL FORMATIONS

HULL SPECIES

Hemiarges paulianus (Clarke)

Cephalon from upper Hull in quarry of Kirkfield Crushed Stone, Ltd., northeast of Kirkfield, Victoria County, Ontario (25552 [catalogue number of specimen, museum of Columbia University] × 3/2); left.

Cephalon from middle Hull in drainage ditch north of road, three-eighths of a mile east of Mount Pleasant, Lennox and Addington County, Ontario (25795, × 3/2); right.

Holotype from basal Prosser of Minnesota—correlated horizon. Species has wide distribution in strata of Hull age in northern Michigan, southern and eastern Ontario, northwestern New York, and along Mohawk Valley; known only from this formation.

Encrinurus cybeliformis Raymond

Cephalon from upper Hull (Crinoid beds) in quarry of Kirkfield Crushed Stone, Ltd., northeast of Kirkfield, Victoria County, Ontario (25616, × 3/2); left. This is the type locality for the species.

Pygidium from basal Hull near crest of hill 2 miles east of Dexter, Jefferson County, New York (25792, × 3/2); right.

Species has wide distribution in beds of Hull age from Ontario to western Vermont.

Parastrophina hemiplicata (Hall)

Dorsal (center) and anterior views of three specimens from base of Hull, Deer River, half a mile west of Deer River village, Lewis County, New York (25799, × 3/2).

Holotype from Hull at Middleville, New York. Abundant in and characteristic of basal Hull in northwestern New York and southern Ontario; species also common in lower Cobourg (Hallowell) in same region; present in Hull equivalents in upper Mississippi Valley and northern Michigan. A more gibbous species is abundant in basal Sherman Fall (Shoreham) along Lake Champlain.

ROCKLAND SPECIES

Phragmolites compressus (Conrad)

Lateral view of specimen from top Rockland (Napanee) in quarry south of road 2 miles west of Gretna, Lennox and Addington County, Ontario, preserving some of crenulate lamellae (25794, × 1); right.

Axial view of external mold of specimen from same horizon and locality (25800, × 1); left.

Holotype probably from Hull, Middleville, New York. Common in Rockland and Hull formations in many localities; not known from higher horizons, which have distinctive species.

Triplecia cuspidata (Hall)

Surface of block of limestone from upper Rockland (Napanee) along House Creek, southwest of Glenfield, Lewis County, New York, showing local abundance of species (25807, × ⅔).

Holotype from same horizon at Lowville, New York; abundant at top of Rockland in southern Ontario and northwestern New York, and in exposures at Inghams Mills, Herkimer County, New York, and Wells, Hamilton County, New York; uncommon in Rockland Isle la Motte limestone along Lake Champlain; known only from upper Rockland.

Bathyurus spiniger (Hall)

Cephalon from limestone slab having *Triplecia cuspidata*, shallow quarry one mile northwest of Wells, Hamilton County, New York (25790, × 3/2).

Holotype from "building stone in Mohawk Valley"; the matrix is black crystalline limestone, and probably of Rockland age. The species is widely distributed in Rockland limestones in New York and Ontario, and is most similar to a species in the lower Decorah (Guttenberg) limestone of the upper Mississippi Valley. *B. ingalli* Raymond, a disinctive Hull species, is readily distinguished, for it has a much longer occipital spine, and is normally larger.

Doleroides ottawanus Wilson

Dorsal and anterior view of two specimens from lower Rockland (Selby) along roadside just northeast of Gretna, Lennox and Addington County, Ontario (25798, × 3/2).

Holotype from lower Rockland at Rockland, Russell County, Ontario. Characteristic of lower Rockland in southern Ontario and northwestern New York; similar species is locally abundant in higher Rockland, and the genus is sparsely represented in the Hull.

Receptaculites occidentalis Salter

Specimen from Rockland (Cloche Island) south of Helen Lake, Cloche Island, Manitoulin District, Ontario (25802, × 1).

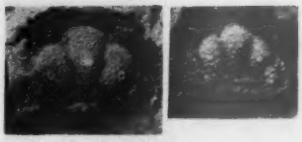
Holotype from equivalent beds at Pauquette Rapids, Pontiac County, Quebec, along the Ottawa River. Common in the Rockland north of Lake Huron and in the upper Ottawa Valley, and in the equivalent Isle la Motte limestone along Lake Champlain. Uncommon in upper Rockland of southern Ontario, and in the Hull limestone of southern Ontario and New York.

Maclurites logani (Salter)

Ventro-lateral view of specimen preserving shell, having ribs on peripheral surface, from Rockland (Cloche Island) a mile northeast of Little Current, Manitoulin District (25804, × ⅝); above. These surface characters are rarely preserved.

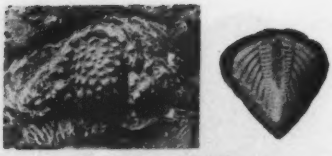
Ventral surface of specimen from same horizon and locality, preserving thin shell (25805, × ⅝).

Holotype from equivalent beds at Pauquette Rapids, Pontiac County, Quebec. The species is common in Rockland beds north of Lake Huron and in upper Ottawa Valley, and in Isle la Motte limestone along Lake Champlain; uncommon in upper Rockland (Napanee) in southern Ontario; the genus has not been found in younger Trenton formations in the region, but other species are known from Cobourg (Stewartville) beds in Michigan and westward, and in the similar upper Liskeard formation of Lake Timiskaming.

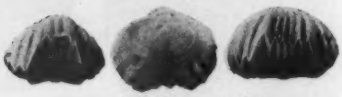


Hemiarges paulianus

HULL

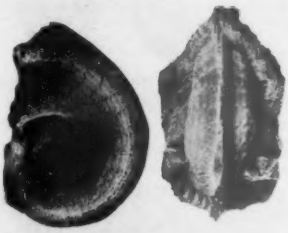


Encrinurus cybeleformis



Parastrophina hemiplicata

ROCKLAND

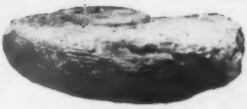


Phragmolites compressus

Triplecia cuspidata

Bathyurus spiniger

Doleroides ottawanus

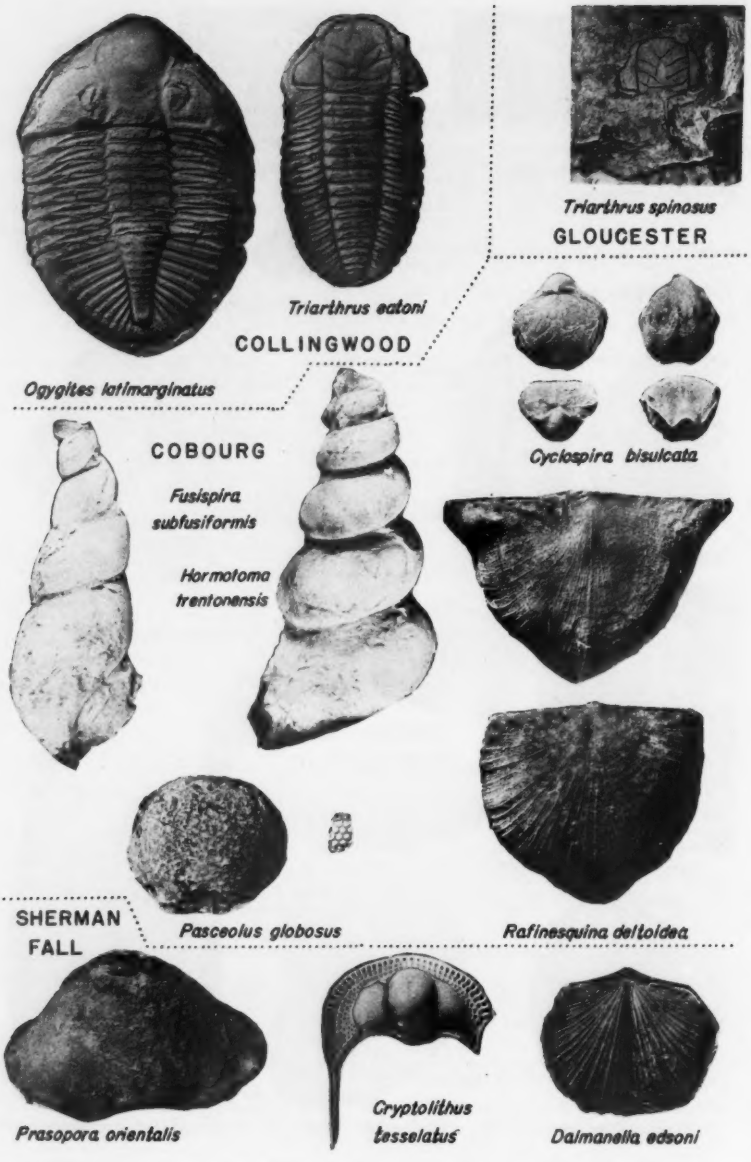


Receptaculites occidentalis

Maclurites logani

Gonioceras groenlandicum

TYPICAL FOSSILS FROM ROCKLAND AND HULL FORMATIONS



TYPICAL FOSSILS FROM SHERMAN FALL, COBOURG, COLLINGWOOD, AND GLOUCESTER FORMATIONS

Gonioceras sp. aff. *G. groenlandicum* Troedsson

Internal mold from Rockland (Cloche Island) from Recollet Point, St. Joseph Island, Algoma District, Ontario (25743, × ½); outline restored from external mold of same specimen.
Holotype of related species from East Greenland. The illustrated species is common in the Cloche Island in Manitoulin District, and frequent in upper Rockland limestones in the upper Ottawa region; another species of the genus is infrequent in the lower Rockland (Selby) of southern Ontario; *G. kayi* Foerste is found in the lower Hull (Ion member—Decorah formation—mistakenly reported from the Guttenberg member in earlier publications) in the upper Mississippi Valley, and a single similar specimen has been found in the Hull near Millington, Victoria County, Ontario.

PLATE 10

TYPICAL FOSSILS FROM THE SHERMAN FALL, COBOURG, COLLINGWOOD AND GLOUCESTER FORMATIONS

GLOUCESTER SPECIES

Triarthrus spinosus Billings

Cephalon from Gloucester shale at Navan, Russell County, Ontario, an internal mold (25488, × ⅝).
Holotype from same horizon and region as illustrated specimen. Species characteristic of Gloucester shale of Ontario; has been found in upper Utica (Holland Patent) in Oneida County, New York.

COLLINGWOOD SPECIES

Ogygites latimarginatus (Hall)

Internal mold of specimen from Craigleith, Grey County, Ontario, just west of Collingwood (25301, × 1).
Holotype supposed to have come from vicinity of Watertown, New York; but lithology seems identical to that of Collingwood shale of Ontario. The species is abundant in the Collingwood from northern Michigan to the Ottawa Valley; is found frequently in uppermost Cobourg (Hillier) in southern Ontario and northwestern New York.

Triarthrus eatoni (Hall)

Specimen from upper Utica (Deer River) shale of Collingwood age, few feet above the Cobourg along Atwater Brook, southwest of Lowville, Lewis County, New York (25299, × ⅝).
Holotype was from Turin, Lewis County, in same horizon as illustrated specimen. The species is characteristic of the Utica (Cobourg, Collingwood and Gloucester) shales of New York, and the similar beds in Ontario; *T. becki* Green of the older Canajoharie (Sherman Fall) has a relatively shorter glabella.

COBOURG SPECIES

Fusispira subfusiformis (Hall)

Internal mold from upper Cobourg (Hillier) west of Wellington, Prince Edward County, Ontario (25796, × ⅝).
Holotype came from equivalent beds near Adams, Jefferson County, New York. Though more common in the upper Cobourg, it is frequent in the lower Cobourg (Hallowell) of southern Ontario and northwestern New York.

Hormotoma trentonensis (Ulrich and Scofield)

Internal mold from same horizon and locality as the last (25793, × ⅝).
Holotype from the upper Cobourg (Hillier) near Adams, Jefferson County, New York. The species has a similar distribution to *Fusispira subfusiformis;* similar species are found in older Trenton formations.

Cyclospira bisulcata (Emmons)

Dorsal, ventral, posterior and anterior views of four specimens from upper Cobourg (Hillier) 40 feet from its base along Deer River, below Copenhagen, Lewis County, New York (25803, × 3/2).
Holotype came from upper Cobourg in western Jefferson County, New York. The species is most common in the middle of that member, but is locally abundant in the upper part of the underlying Hallowell member.

Rafinesquina deltoidea (Conrad)

Ventral views of two specimens, showing variation in form; each came from the same slab from the top of the lower Cobourg (Hallowell) along Moose Creek west of the State Highway in southern Lewis County, New York (25534, 25801, × 3/2).
Holotype from same horizon at Trenton Falls, Oneida County, New York. Typical deltoid specimens of the species are characteristic of the top lower Cobourg; forms approaching the typical *R. deltoidea* are uncommon at other horizons.

Pasceolus globosus Billings (= *"Ischadites* sp.")

Lateral view of specimen from basal bed of lower Cobourg (Hallowell) 325 feet above the base of the Trenton group (stratigraphically) along Mill Creek, Lowville, New York (25573, × ½); left.
Fragment showing surface form from middle of lower Cobourg (Hallowell) 35 feet above west side of Lake of the Mountain, Glenora, Prince Edward County, Ontario.
Holotype from undefined horizon in Trenton near Ottawa, Ontario. The species has been found commonly at Lowville and near Amelisburg, Prince Edward County, Ontario, at about the Sherman Fall-Cobourg contact; the horizon has been arbitrarily considered the base of the Cobourg because of the presence of the species higher in the formation; it was originally assigned to the top of the Sherman Fall.

SHERMAN FALL SPECIES

Prasopora orientalis Ulrich

Specimen from the basal Sherman Fall (Shoreham) along Stony Creek, south of Middleville, Herkimer County, New York (25809, × ½).

The species was not originally illustrated, and was stated to come from Ottawa and Peterborough, Ontario, and Trenton Falls, New York; it is common and characteristic of the Sherman Fall formation from Ontario to Vermont, being particularly abundant in the basal (Shoreham) member. Specimens having the typical form reach diameters of 5 inches, but gerontic, irregular forms have been collected having twice that diameter.

Cryptolithus tesselatus Green

Specimen from the basal Sherman Fall, upper Glens Falls, Shoreham limestone from the quarries half a mile southwest of Pattersonville, Schenectady County, New York (25590, × 3/2); right genal spine lost during life.

This species is frequent to abundant in the basal Sherman Fall (Shoreham) from southern Ontario to the region of Lake Champlain; it has never been found in beds older than the Shoreham, nor does it seem to be in limestones younger than the Shoreham. It is found, however, in younger Sherman Fall shales in eastern Vermont.

Dalmanella edsoni Bassler

Specimen from the basal Sherman Fall (Shoreham) at Larrabee Point, Addison County, Vermont (25797, × 5/4).

Holotype from same horizon at Highgate Springs, northwestern Vermont. This very large species of the genus has been found at that horizon in several sections along Lake Champlain, but has not been recognized in western New York or Ontario.